TM 1-413

WAR DEPARTMENT TECHNICAL MANUAL

AIRCRAFT INSTRUMENTS

WAR DEPARTMENT • JUNE 1946

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This manual supersedes TM 1-413, 2 February 1942.

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SECTION I
GENERAL

1. General

Human limitations make it impossible for a pilot, using his senses alone, to cope with all the climatic conditions and mechanical devices involved in the flight of an airplane. Aircraft instruments give him invaluable assistance by indicating these conditions and the reactions of the many mechanisms. The dials of various instruments, located conveniently on the panel before him, record variations in temperature, pressure, speed, altitude, direction, drift, and attitude, and also indicate the mechanical condition of the engine. Even when it is impossible for the pilot to see the ground, reliable instruments provide him with all the information he needs to maintain flight.

2. Design Characteristics

a. Although there are many types of instruments, the demands of modern aviation make it necessary that all instruments meet certain requirements.

b. Instruments must be light, because excessive weight in an airplane will retard its speed and effectiveness.

c. Instruments must be small, because the space available for them is limited.

d. Every instrument must be easy to read. Luminous paint applied to the pointer and markings facilitate reading at night. Some instruments have built-in receptacles which hold 3-volt lamps to give further assistance to the pilot in reading the dials. Other instrument dails are marked with a material that glows *only* when exposed to light from fluorescent cockpit lamps.

e. All instruments must be perfectly balanced and must indicate accurately, regardless of their positions and the effects of centrifugal forces encountered in flight.

f. Instruments are designed to function accurately only when subjected to some vibration, because vibration is always present during flight even though the instrument panel is shockproof to some extent. (See par. 76.)

g. Close proximity to other instruments on the panel makes it necessary for each instrument to be "immune" to the effects of magnetic fields. Some form of magnetism is active within every electrical instrument. Special cases prevent the magnetic flux from escaping from one instrument to another and causing inaccurate indications.

h. Each instrument mechanism must be inclosed in a dustproof and rainproof case which is light and durable and resists corrosion. Cases are usually made of phenolic composition, but when an instrument weighs more than 5 pounds, an aluminum case is used. The glass is made raintight by the pressure of a snap ring which holds it against a rubber gasket.

i. Any instrument should give at least 1,000 hours of satisfactory performance between major overhaul (to be accomplished at air depots only). To insure mechanical perfection, rigid tests are made at the time the instrument is purchased, and careful maintenance and operation tests must be conducted while the instrument is in use.

3. Inspection and Maintenance

a. Aircraft instruments are designed to operate properly under ordinary flight conditions, but malfunctions may develop at any time; therefore it is necessary to maintain a rigid system of periodic inspections, tests, and repairs to insure the accuracy and general usefulness of the instruments. Any one of the following conditions, or a combination of several, may cause partial or complete failure of an instrument:

(1) Excessive vibration.

(2) Hard landings.

(3) Violent aerobatics (particularly applicable to uncaged gyros).

(4) Abnormal pressures.

(5) Excessive temperatures.

(6) Seasoning and aging of sensitive elements.

(7) Overtightening of mounting screws and connections.

b. The crew chief is responsible for the proper inspection and maintenance of the instruments, and he must be able to use them for intelligent diagnoses of engine troubles.

c. Repair, inspection, and maintenance of aircraft instruments may be divided into major repair, base repair, and line maintenance. The scope of the work performed in each of these classifications is definitely outlined in Technical Orders and, in general, is based on the facilities which have been made available to the agencies doing the work. It is important,

therefore, that all maintenance personnel be informed as to the limits and restrictions placed on instrument repair.

(1) Major repairs are performed at depots only and include all repair work that requires particular skill, special tools, jigs, and calibration equipment. Luminous paint is applied, parts are replaced, and adjustment of internal mechanisms is made under this classification.

(2) Base repairs are made at stations having base squadrons or detachments which function as the equivalent thereof. This work consists of bench tests and minor repair operations beyond the scope of line maintenance.

(3) Line maintenance is the authorized instrument work performed by the crew chief and his assistants. It consists of the daily, preflight, 25-, 50-, and 100-hour inspections, such maintenance as may be required at these inspections, and the removal and replacement of instruments.

d. Daily Inspection. During daily inspections the pointers are checked for excessive error at zero (except thermometers and absolute pressure-operated instruments which show indications consistent with surrounding conditions). The instruments are checked for loose or cracked cover glasses; the lights are checked; and caging and setting knobs are inspected for freedom of movement and correct operation.

e. Preflight Inspection. Preflight inspections are made by the crew chief on airplanes prior to the first flight of the day. The instrument pointers are checked for excessive oscillation and the readings for consistency with engine requirements and speeds.

f. Fifty-Hour Inspection. During the 50-hour inspection the crew chief (often assisted by an instrument mechanic) checks:

(1) Instruments and dependent units for security of mounting.

(2) Lines and connections for leaks.

(3) Dial markings and pointers for dull and discolored luminous markings.

(4) Operation markings for correctness and discernibleness.

(5) Electrical and bonding connections for good contacts and security of attachment.

(6) Vibration absorbers for security of attachment and proper tension.

SECTION II
PRESSURE GAUGES

4. General

a. Pressure gauges, like other aircraft instruments, were designed to help the pilot operate his airplane more safely and efficiently. They warn him of trouble and allow time to correct the trouble or find a suitable landing field before any serious condition results. It is therefore important that pressure gauges give accurate indications at all times. These gauges are used for several purposes. They may indicate:

(1) Pressure at which lubricating oil is being furnished to the engine.

(2) Pressure at which fuel is being pumped to the engine.

(3) Pressure available for operating hydraulic units—the landing gear, brakes, flaps, etc.

(4) Pressure available for operation of the rubber de-icer boots.

(5) Suction available for operating the air-driven gyroscopic instruments.

(6) Pressure in the intake manifold of the engine under various operating conditions.

b. There are four general types of pressure gauges:

(1) Bourdon-tube type.
(2) Diaphragm type.
(3) Aneroid type.
(4) Opposed-bellows type.

5. Principle of Operation

a. Bourdon-tube Gauges. All Bourdon-tube pressure gauges are similar in construction and principle of operation, although they may be used for indicating various amounts of pressure. Rigid tubing or a combination of rigid and flexible tubing is used to connect the inlet at the back of the instru-

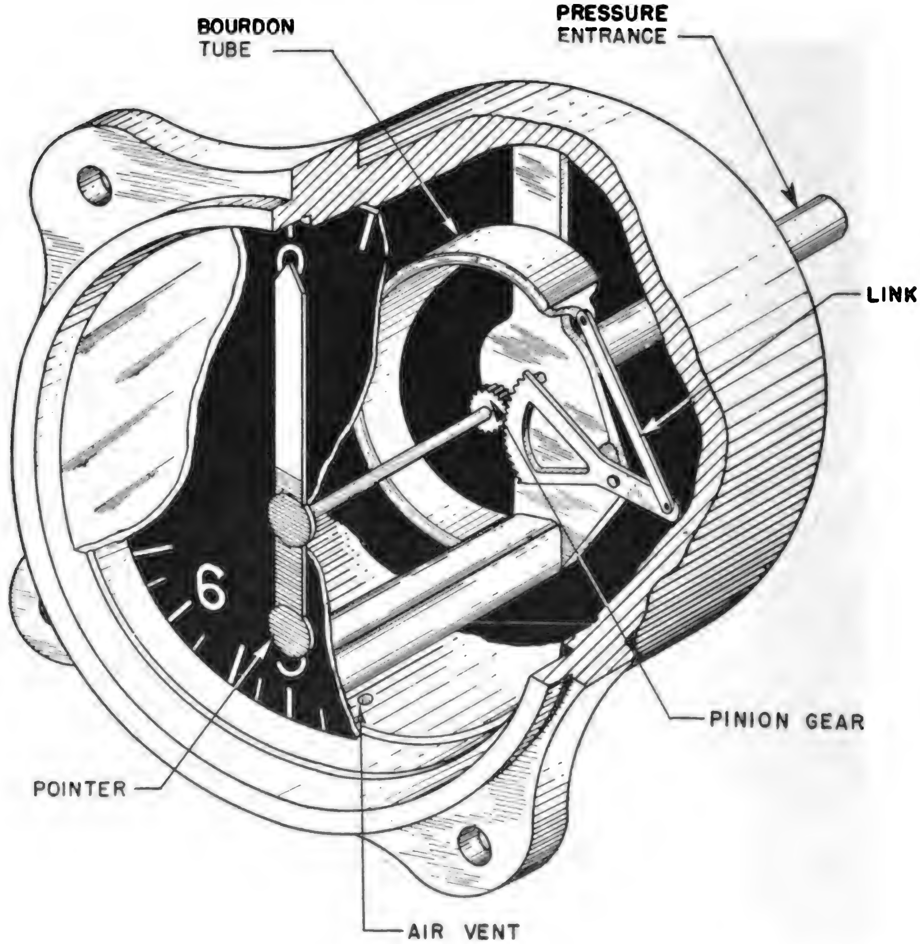


Figure 1. Bourdon-tube pressure gauge.

ment case to the point at which the pressure is to be measured. The pressure (oil, fuel, or air) goes through this tubing and into the Bourdon tube. The Bourdon tube which is elliptical in cross-section and sealed at the outer end, is made of phosphor-bronze or beryllium copper. This outer end is free to move and is connected to a link, lever, and pinion which control the pointer, as shown in figure 1. The end of the Bourdon tube, which is fastened to the instrument case, is stationary at all times. Because of its construction, the Bourdon tube acts like a spring and tends to straighten out when internal pressure is applied. This straightening tendency is resisted on the outside surfaces of the tube by atmospheric pressure which is admitted to the case by a small vent (fig. 1) in the bottom of the case or by pressure introduced by means of a tubing connection attached to the instrument case. The gauge indicates the difference between the vent pressure and the pressure inside the tube and is called a differential-pressure measuring device. Any indication that it gives is caused by the pressure inside the tube differing from that on the outside. The tube will always return to its normal position when the pressure is released. All Bourdon tubes operate in this manner but a heavier tube will be required when the instrument is used for extremely high pressures.

b. Diaphragm Gauges. This type of pressure gauge (fig. 2) uses a circular, hollow disk or diaphragm for measuring pressure. The pressure or suction to be measured is admitted to the pressure-sensitive diaphragm through an opening in the back of the case. An opposing pressure, such as that of the atmosphere, is admitted through a vent in the case. Since the walls of the diaphragm are very thin, an increase of pressure will cause it to expand and a decrease in pressure will cause it to contract. Any movement of the diaphragm is transferred to the pointer by means of the rocker shaft, sector, and pinion, which are connected to the front side of the diaphragm. This gauge is also a differential-pressure measuring device since it indicates the difference between the pressure applied at the vent of the case and the pressure or suction inside the diaphragm.

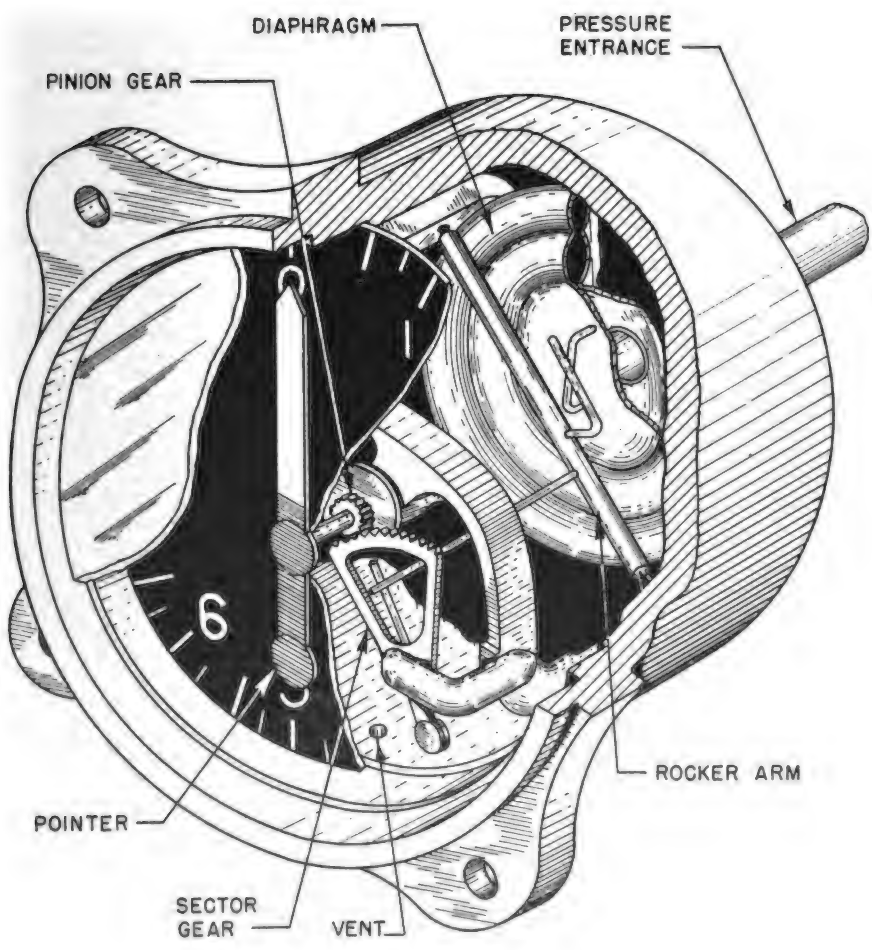


Figure 2. Diaphragm type pressure gauge.

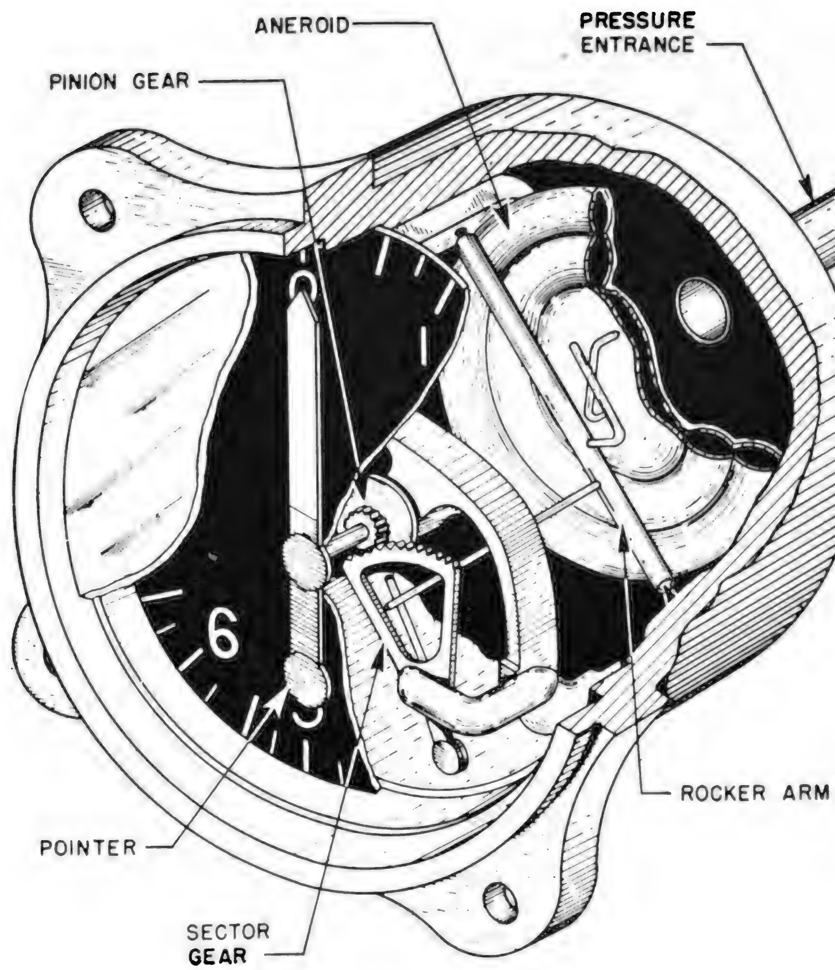


Figure 3. Aneroid type pressure gauge.

c. Aneroid Gauges. An aneroid (fig. 3) consists of two thin, metal, corrugated disks soldered together to form an airtight chamber. It differs from a diaphragm in that the aneroid is sealed, while the diaphragm has an opening to receive the pressure which is being measured. The air is removed from the aneroid and the pressure to be measured is admitted to the case of the instrument. The pressure inside the aneroid is constant, therefore the amount of pressure measured is direct or absolute and the gauge is not a differential-pressure measuring device.

d. Opposed-bellows Gauges. This type of gauge (fig. 4) employs two opposed flexible metallic bellows having equal, effective areas. One, the vacuum bellows, is completely evacuated, and the other, the pressure bellows, is connected by tubing to a ⅛-inch outlet which protrudes through the rear of the case. Each bellows has a stationary head and a movable head. The two stationary heads are rigidly attached to the instrument frame; the movable pressure-bellows head and the movable vacuum-bellows head are attached to each other by a spacer sleeve. A helical, tension spring is wholly inclosed in the pressure bellows, and is fastened to the stationary pressure head and the movable pressure head by threaded end pieces. Since the vacuum bellows is completely evacuated, the helical spring will always be under tension when the pressure in the pressure bellows is other than absolute zero. The pressure being measured will be absolute; any increase will cause the movable pressure-bellows head and the spacer sleeve, and therefore the movable vacuum-bellows head, to move to the right. Since the two opposed bellows have equal, effective areas, the effect of changes in external barometric pressure is balanced out, and movement of the bellows is independent of this pressure. Deflection of the bellows is, therefore, entirely a result of the changes in the absolute pressure in the pressure bellows. This deflection is transmitted to the pointer by means of mechanical linkage attached to the movable pressure-bellows head.

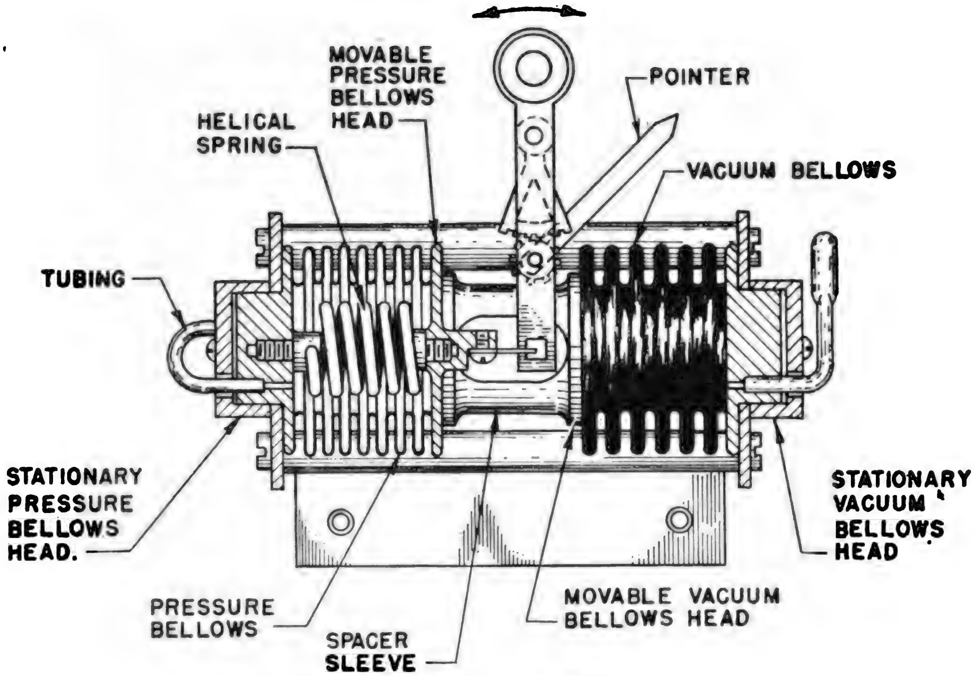


Figure 4. Mechanism of opposed-bellows type pressure gauge.

e. On some units, an A-1 type pressure transmitter is installed close to the source of pressure. A low-viscosity fluid, similar to kerosene but known as compass liquid, is used between the transmitter and the indicator.

(1) By use of this transmitter, viscous engine oil will be confined to the inlet of the transmitter where the engine heat will keep it relatively thin; inflammable fuels and oils will remain inside the firewalls, thus reducing fire hazard; fuel or lubricant will not be drained from the engine if a leak occurs in the indicator line.

(2) The transmitter shown in figure 5①, is an aluminum cell divided into two chambers by a flexible diaphragm, corrugated to permit free displacement as the pressure is increased or decreased. Normally, the diaphragm serves only to prevent the fuel or oil in one chamber from mixing with the fluid in the other. If the line to the indicator, shown in figure 5②, should break or be shot away, the fluid will run out and the diaphragm will seal the small passage by which pressure is normally conveyed to the line. A similar action will take place if a small leak develops in the line to the indicator. Consequently, it is imperative that the system be kept entirely free from leaks.

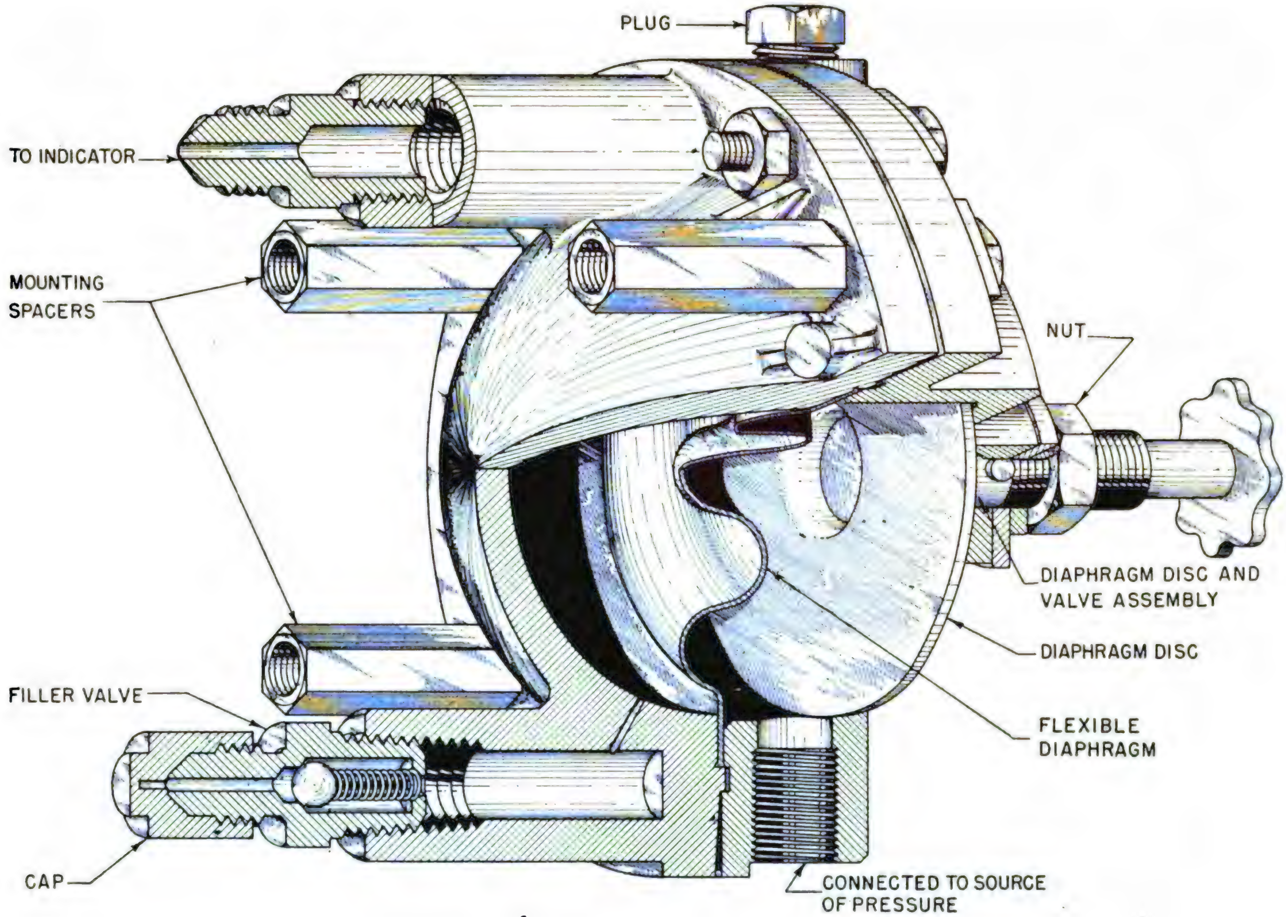
(3) Before the outlet chamber, line, and indicator are filled with fluid, the nut on the diaphragm disk and valve assembly must be turned off the threads, and the knob pushed inward and turned clockwise until firmly in place against the diaphragm. Fluid is pumped through the filler valve until no air bubbles flow from the bleed valve close to the indicator. After the system is filled, the filler and bleed valves are capped, and the disk and valve assembly returned to its original position.

(4) When the inlet chamber is filled with air-free fuel or oil, there will be little or no movement of the noncompressible fluids, but pressure changes will be accurately transmitted to the diaphragm and the indicator.

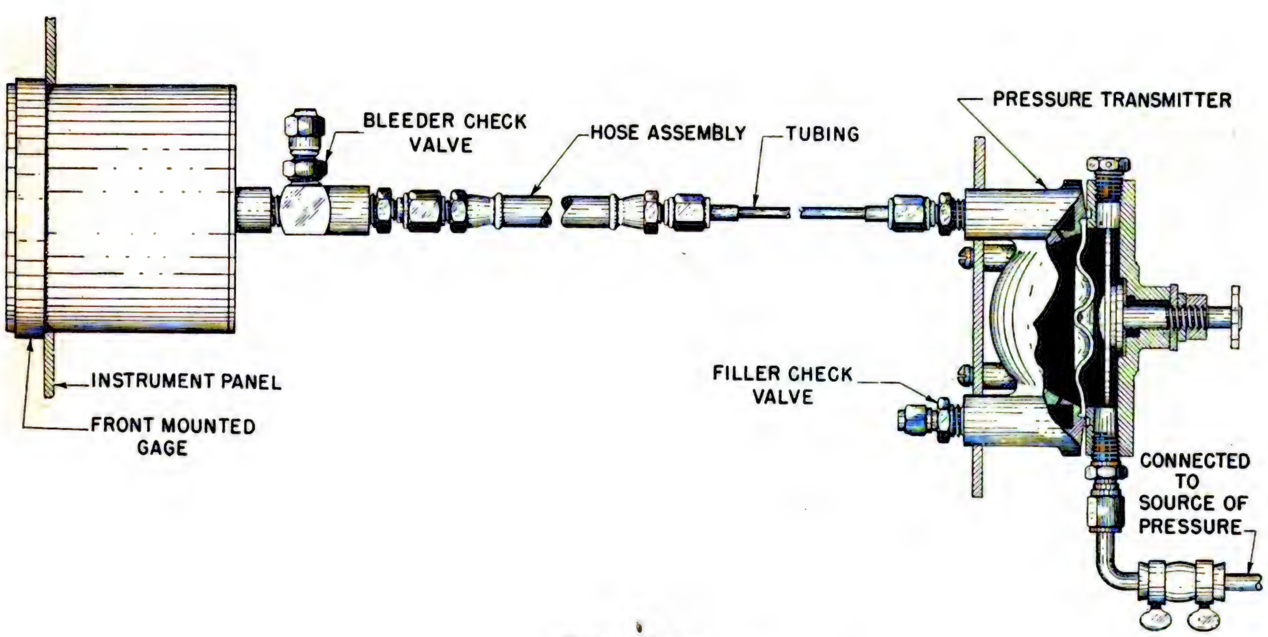
6. Applications

a. Oil-pressure Gauge. The oil-pressure gauge indicates the pressure under which oil is being supplied to the lubricating system of the engine. (See fig. 6.) This gauge warns the pilot of impending engine failure due to an exhausted oil supply, failure of the oil pump, burned-out bearings, broken oil lines, and other causes which may be indicated by a loss of pressure.

(1) The standard type of oil-pressure gauge (fig. 7) is a differential-pressure measuring device using a Bourdon-tube mechanism. This gauge is constructed the same as other Bourdon-tube gauges except that it has a small restriction built into the case or into the nipple connection leading to the Bourdon tube. This restriction prevents the surging action of the oil pump from damaging the gauge or causing the pointer to oscillate too violently. The



① *Pressure transmitter.*



② *Installation.*

Figure 5. A-1 pressure transmitter and installation.

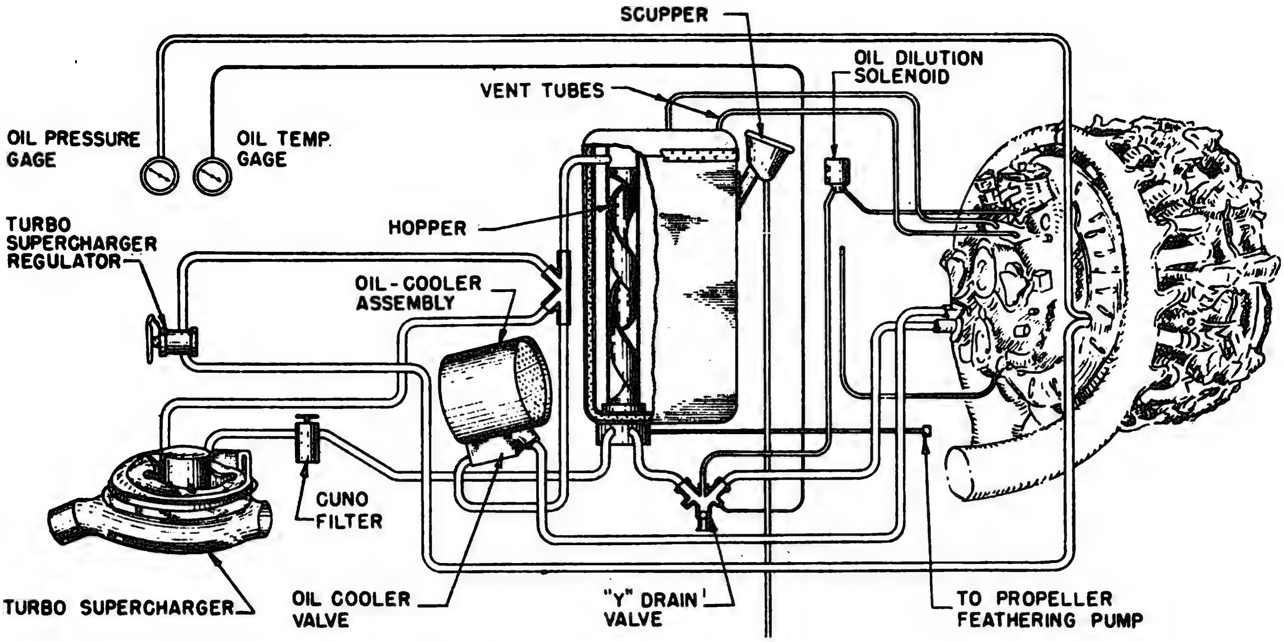


Figure 6. Oil-pressure gauge installation.

① *Front view.*

③ *Rear view.*

Figure 7. Oil-pressure gauge.

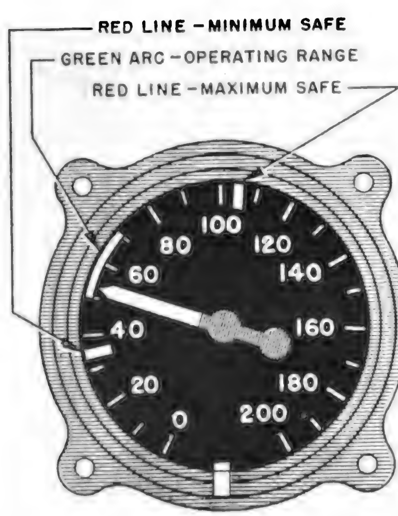


Figure 8. Oil-pressure gauge operation markings.

oil-pressure gauge has a scale range from 0 to 200 or 0 to 300 pounds per square inch. Operation markings are placed on the gauge to indicate the safe range of oil pressure for a given installation. (See fig. 8.) Oil pressures normally run from 60 to 90 pounds per square inch.

(2) A dual-type oil-pressure gauge is available for use on multiple engine aircraft. The dual indicator contains two Bourdon tubes housed in a standard aircraft type case, one tube being used for each engine. The connections extend from the back of the case to the respective engine. There is one common movement assembly but the moving parts function independently. Pointers now marked *R* and *L* are being changed to read *1* and *2* or *3* and *4* to avoid confusion on four-engine airplanes. The *1* and *2* markings will be used on two-engine airplanes.

(3) During cold weather the oil-pressure gauge may fail to indicate properly when the engine is first started. To prevent sluggish operation, which results from the use of thick, cold oil, the line leading to the gauge is disconnected, thoroughly drained, and refilled with light oil.

(4) Three systems have been devised to alleviate sluggishness of oil-pressure and fuel-pressure gauges in cold weather as a result of the gauge-line fluid becoming stiff. Each of these systems requires a special servicing procedure. The three systems are as follows:

(*a*) *Type A-1 pressure transmitter system.* This system interposes a second free-flowing, nonfreezing, nonhazardous liquid between the pressure source and the pressure gauge. This is accomplished by means of a pressure transmitter which transfers the oil pressure to the free-flowing, nonfreezing, nonhazardous liquid. The two liquids are separated by a flexible, pressure-transmitting diaphragm located between the two halves of the transmitter. (See fig. 9.) The oil pressure is transferred, without loss, to the pressure indicating instrument. In weather below —26°C. (—14°F.), sluggish operation may be experienced because of the oil congealing in the short line from the transmitter to the engine. This can be overcome by filling the line with a low-viscosity fluid such as hydraulic fluid. With the pressure-transmitter system, it is important that a quantity of liquid be kept in the reservoir of the master gauge unit at all times to prevent air from entering the transmitter system. The filling of the pressure-gauge side of the transmitter may be accomplished by use of either a portable filler gun (fig. 9) or a master pressure-gauge unit (par. 98*f*). In either case, the line is serviced as indicated in figure 9; the portable filler gun or master-gauge unit is connected to the lower filler check valve (stamped "F") of the transmitter, the cap removed from the instrument check valve, and a bleed line attached. The charging is continued until no air bubbles appear at the end of the bleed line. If a master-gauge is used for filling the line, make sure that all oil is first removed from the master-gauge unit prior to filling with the free-flowing, nonfreezing liquid (compass liquid or hydraulic fluid).

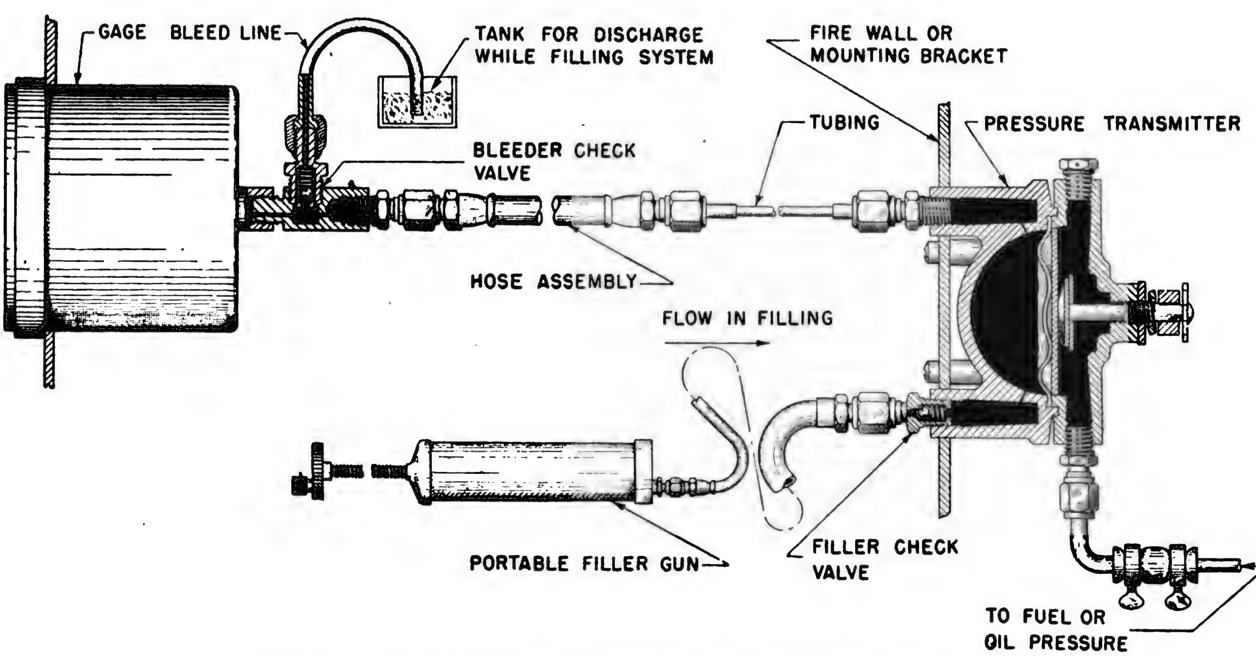


Figure 9. Type A-1 pressure-transmitter system—showing method of filling.

(*b*) *Direct-connected oil-pressure gauge system.* This system consists of a line connected directly from the engine to the back connection of a conventional type oil-pressure gauge on the instrument panel. When cold-weather operation of aircraft is anticipated with resultant sluggishness in gauge operation, the oil-pressure line is filled with hydraulic fluid. The filling is accomplished through the filler check valve. (See fig. 10). Refilling the system should not be necessary until sluggishness is again noted.

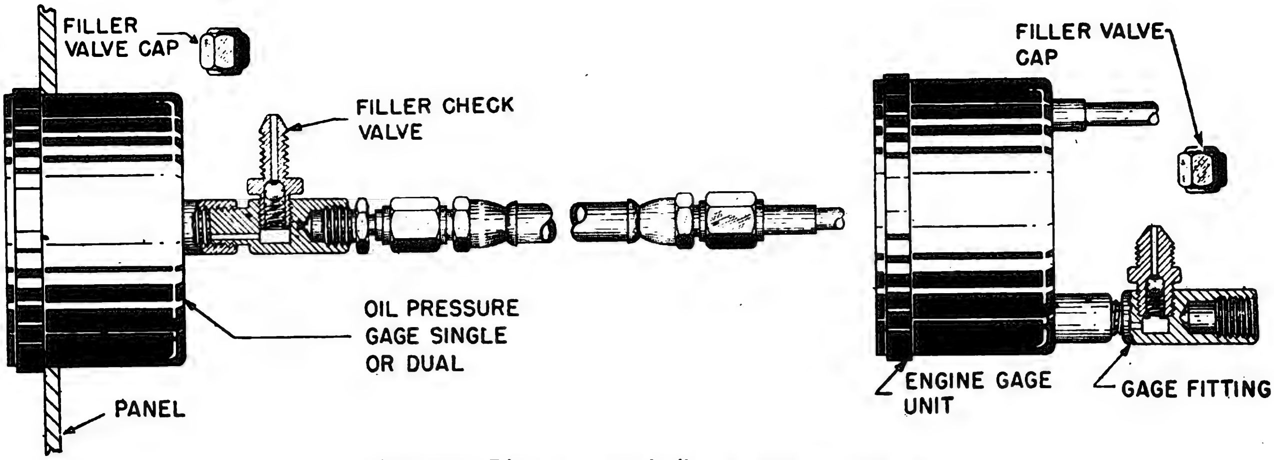


Figure 10. Direct-connected oil-pressure-gauge system.

(*c*) *Panel serviced type, direct-connected oil-pressure gauge system.* In order to facilitate quicker service for direct-connected oil-pressure gauge systems, the panel type system was developed. This system differs from the conventional direct-connected oil-pressure gauge system in that a line is connected to the filler check valve in back of the instrument and extended through the panel, as shown in figure 11. This enables the mechanic to service

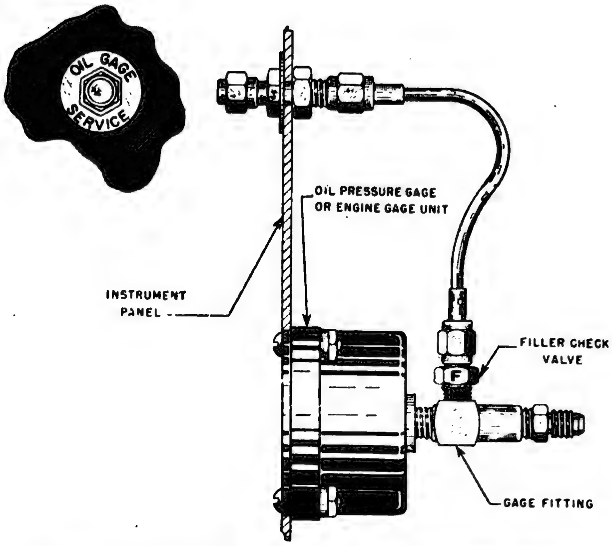


Figure 11. Panel-serviced type of oil-pressure-gauge system.

the line by connecting a filler gun to the fitting protruding from the instrument panel. The system need not be reserviced until such time as sluggish operation of the oil-pressure gauge is again noted.

b. Fuel-pressure Gauge. The fuel-pressure gauge (fig. 12) indicates the amount of pressure being produced by the fuel pump which keeps fuel flowing to the engine. This gauge will warn the pilot

① *0 to 10-pound gauge.*

② *0 to 23-pound gauge.*
Figure 12. Fuel-pressure gauges.

of any condition, such as a broken or clogged fuel line, failure of the fuel pump, or interrupted flow of fuel when a switch is made from one fuel tank to another, which prevents the fuel from reaching the carburetors under sufficient pressure.

(1) The standard fuel-pressure gauge is sealed airtight and contains a Bourdon type mechanism. This gauge may be used on either internally or externally supercharged engines. The gauge has two nipples in the back of the case, marked "Fuel" and

"Air" or "Pressure" and "Air", which connect the instrument to the engine fuel system. On some internally supercharged engines, only the "Fuel" connections are made. (See fig. 13.) In these cases, the air vents remain open and the air pressure in

(3) Dual fuel-pressure gauges are intended for use in multiple-engine airplanes and use two, opposed, flexibles, metallic bellows for each pointer. Air pressure is admitted to one side of the bellows and fuel pressure to the other.

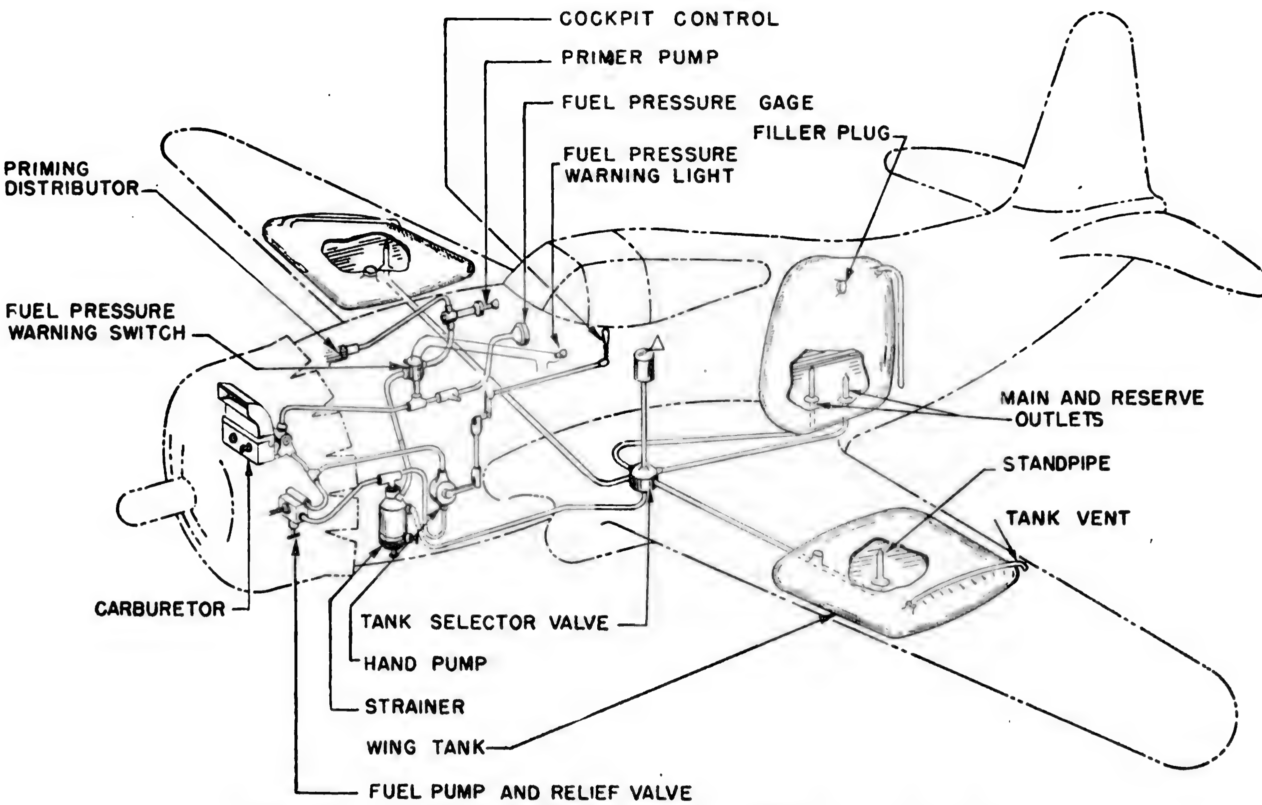


Figure 13. Fuel-pressure gauge installation—internally supercharged engine.

the instrument cases will be atmospheric or cockpit pressure. On other internally supercharged engines the air vents are connected to the air chambers of the carburetors. On an externally supercharged engine, the air inlet is connected to the air pressure chamber of the supercharger. (See fig. 14.) In any of the installations, the resulting gauge reading is that difference between the pressure of the fuel and the air at the carburetor inlets.

(2) Another type fuel-pressure unit uses a small diaphragm type transmitter. This transmitter is installed as close as possible to the source of pressure. The pressure is applied directly to one side of the diaphragm. A low-viscosity fluid fills the space on the other side of the diaphragm and also fills a tube of small diameter. This tube connects to a standard type indicating instrument and the fluid pressure from the transmitter actuates the indicator. A mechanism is provided to "center" the diaphragm while this unit is being bled or filled.

(4) Fuel-pressure gauges used with pressure-discharge carburetors have ranges of 0 to 25 pounds per square inch, normal fuel pressure being 12 to 17 pounds per square inch. The gauges used with other types of carburetors have ranges of 0 to 10 pounds per square inch, normal fuel pressures being 3 to 6½ pounds per square inch, or 6 to 9 pounds per square inch. The tolerance at zero of either type is ± 0.3 pounds per square inch. Figure 15 shows sample operation markings.

c. Engine-gauge Unit. (1) This instrument is a combination of a fuel-pressure gauge, an oil-pressure gauge, and an oil thermometer (described in sec. III) combined in one instrument case under one cover glass. This arrangement saves space on the instrument panel and with a minimum of effort, allows the pilot, to observe the pressures in the lubricating and fuel-feed systems and the temperature of the engine oil. Each instrument maintains its separate function and has its own pointer and scale. (See fig. 16.)

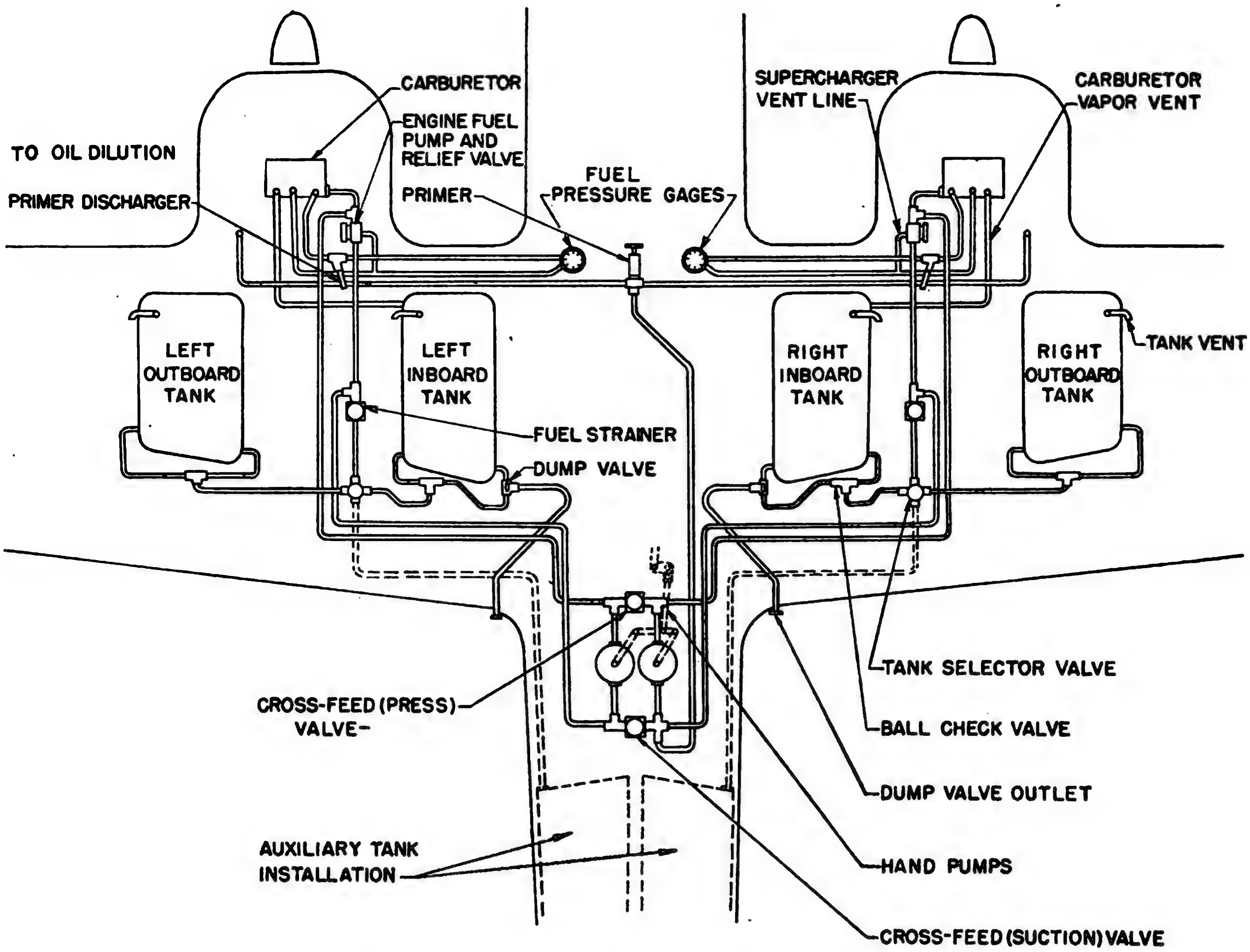
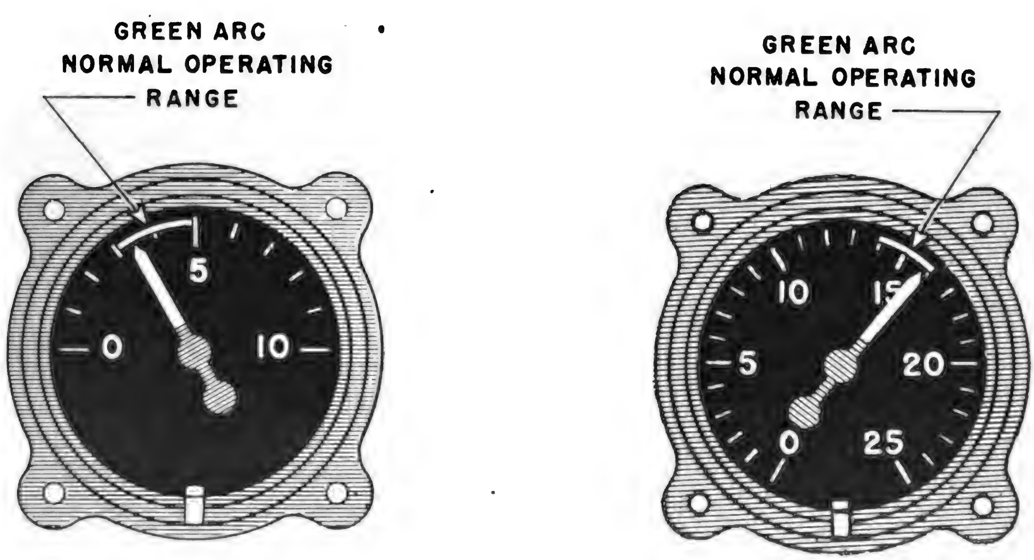


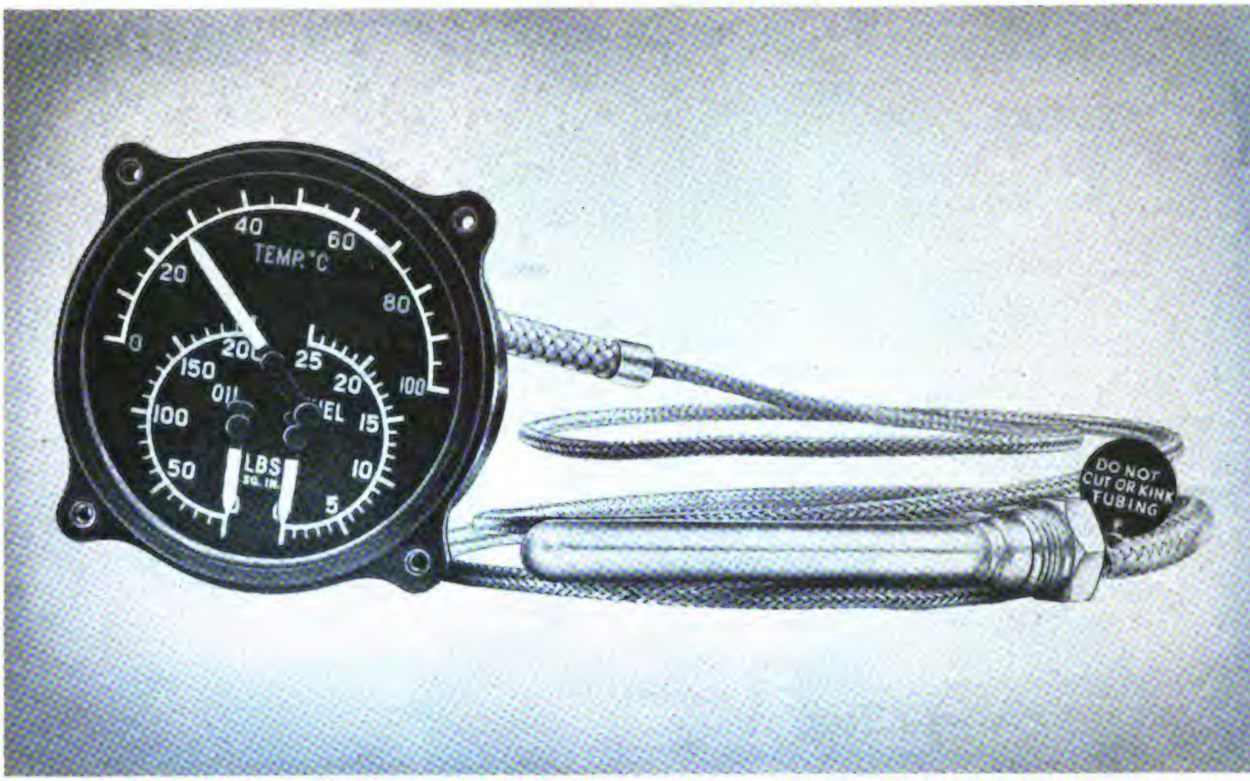
Figure 14. Fuel-pressure gauge installation — externally supercharged engine.



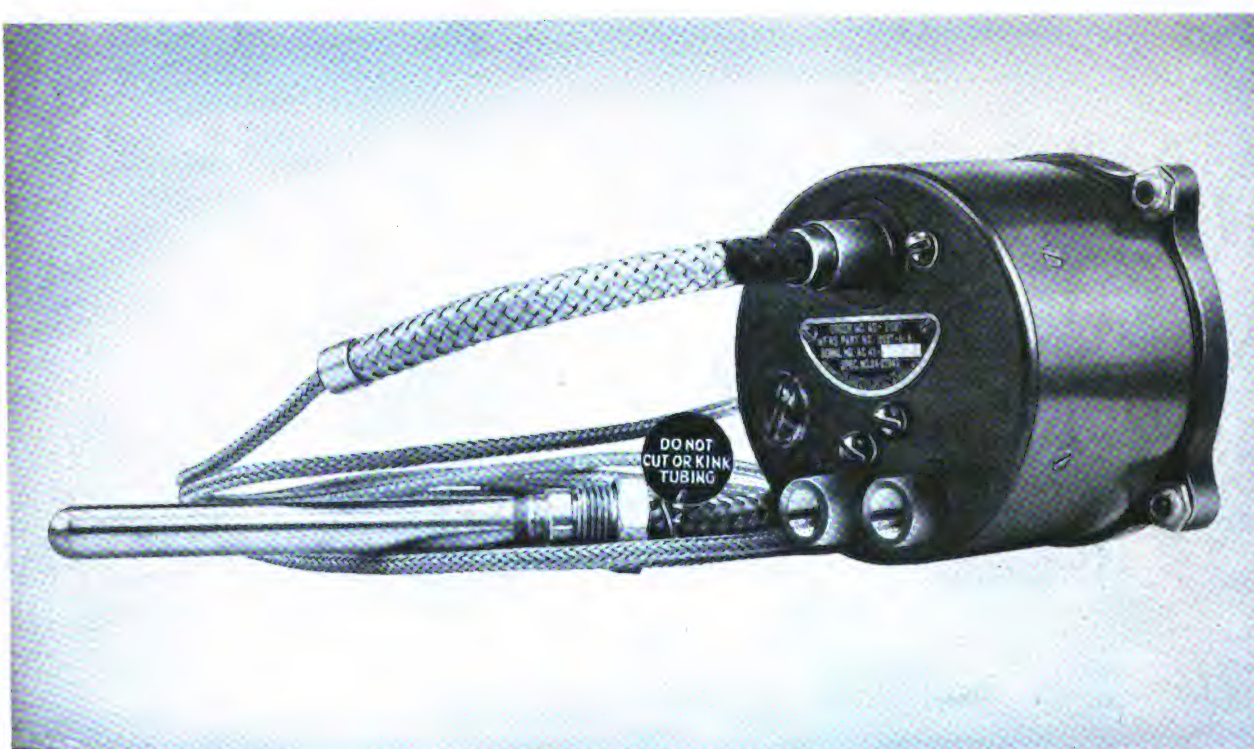
① *0 to 10-pound gauge.*

② *0 to 25-pound gauge.*

Figure 15. Sample fuel-pressure-operation markings.



① *Front view.*



② *Rear view.*
Figure 16. Engine-gauge unit.

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(2) One type of engine-gauge unit employs three Bourdon-tube mechanisms, one for each of the three functions to be measured. Another kind consists of an electrical type Wheatstone-bridge oil thermometer and two Bourdon tubes to measure the oil and fuel pressures. A third variety consists of the resistance-bridge electrical type thermometer, a Bourdon tube for the oil-pressure gauge, and a fuel-pressure gauge containing two Bourdon tubes which indicate the difference between the pressure applied to the fuel vent and that applied to the air vent. Tube nipples are located on the back of the instrument for line connections to the fuel and oil systems.

(3) When the three units of this gauge are connected to the engine, the oil-pressure line and the fuel line must be attached to their respective connections (marked "Fuel" and "Oil"), on the back of the instrument case; otherwise serious damage to the mechanisms will result when the engine is started.

(4) The engine-gauge unit measures fuel pressures from 0 to 10, or 0 to 25 pounds per square inch; oil pressures from 0 to 200 pounds per square inch, and oil temperature from 0°C. to 100°C. or —70° to 150°C. Tolerances are the same as for the instruments the engine-gauge unit replaces. If any of the three units of this gauge becomes inoperative, it is necessary to remove and replace the entire assembly. Maintenance for the units in this gauge is the same as that described for individual gauges.

d. Suction Gauge. (1) The purpose of the suction gauge is to indicate the amount of suction that is available for operation of the air-driven gyroscopic instruments. Any reduction in the pressure or suction, below that specified as normal for actuating gyroscopic flight instruments, will impair their functioning. Therefore, a means must be provided to inform the pilot continually of the exact amount of suction being provided. Suction gauges are used also to give an indication of leaks in the vacuum system and to facilitate the proper adjustment of the system relief valve.

Figure 17. Suction gauge-bellows type.

(2) The suction gauge may have a pressure-sensitive element of the diaphragm or bellows type. The gauge shown in figure 17 is of the bellows type and has one inlet on the rear of the case. The gauge shown in figure 18 is of the diaphragm type and has two connections (marked "Suction" and "Vent") on

① *Front view.*

② *Rear view.*
Figure 18. Suction gauge—diaphragm type.

the rear of the case. If the former type is used, the opening on the rear of the case will be connected to the suction line. If the latter is used, the opening marked "Suction" is usually connected to the flight indicator at the air outlet and the one marked "Vent" is usually connected to a point between the flight indicator and air filter, as shown in figure 19. This is done in order to show the correct pressure differential across the instrument. Both types of gauges have scale ranges of from 0 to 10 inches of mercury (Hg), and the normal suction gauge reading is 3¾ to 4¼ inches Hg. The suction gauge has a tolerance at zero of ±0.1 inch Hg.

e. Manifold-pressure Gauge. The manifold-pressure gauge (fig. 20) indicates the manifold (supercharger) pressure of an aircraft engine equipped with a supercharger. Operation of an engine with too much manifold pressure will seriously damage the engine. Too little pressure will result in decreased horsepower output.

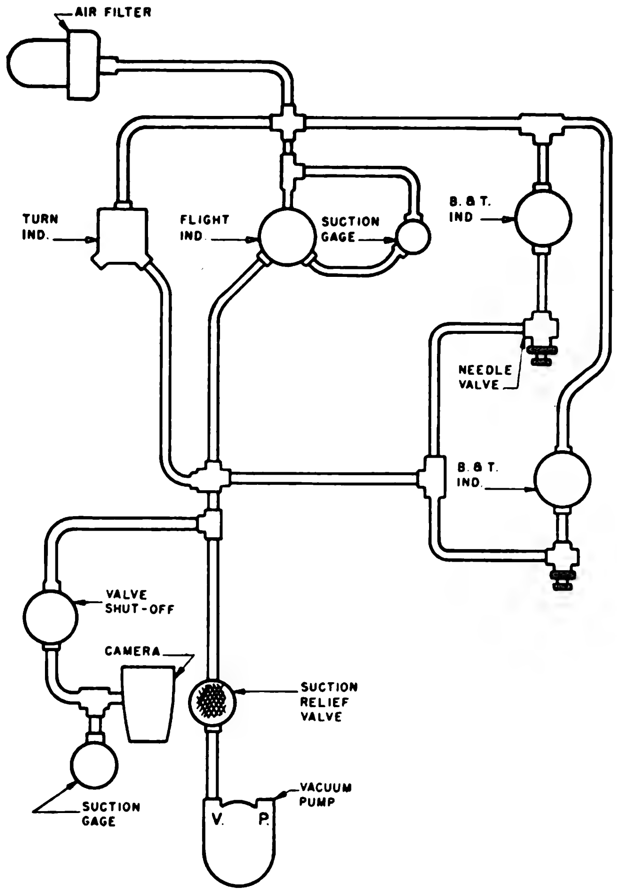


Figure 19. Location of suction gauges in vacuum system.

(1) The aneroid type gauge is frequently used to indicate manifold pressure. The pressure to be measured enters the case through the connection in the back and fills the entire case. The corrugated walls are acted upon by this pressure and the absolute pressure is transmitted to the pointer by means of the mechanical linkage illustrated in figure 3. The pointer travels over a dial graduated in inches of mercury.

(2) The opposed bellows type gauge, described in paragraph 5*d*, is also used to indicate manifold pressure.

(3) A third type of manifold-pressure gauge (fig. 21), contains an aneroid-diaphragm assembly which is sealed inside a pressure chamber. The manifold pressure enters the pressure chamber through

Figure 20. Manifold-pressure gauge.

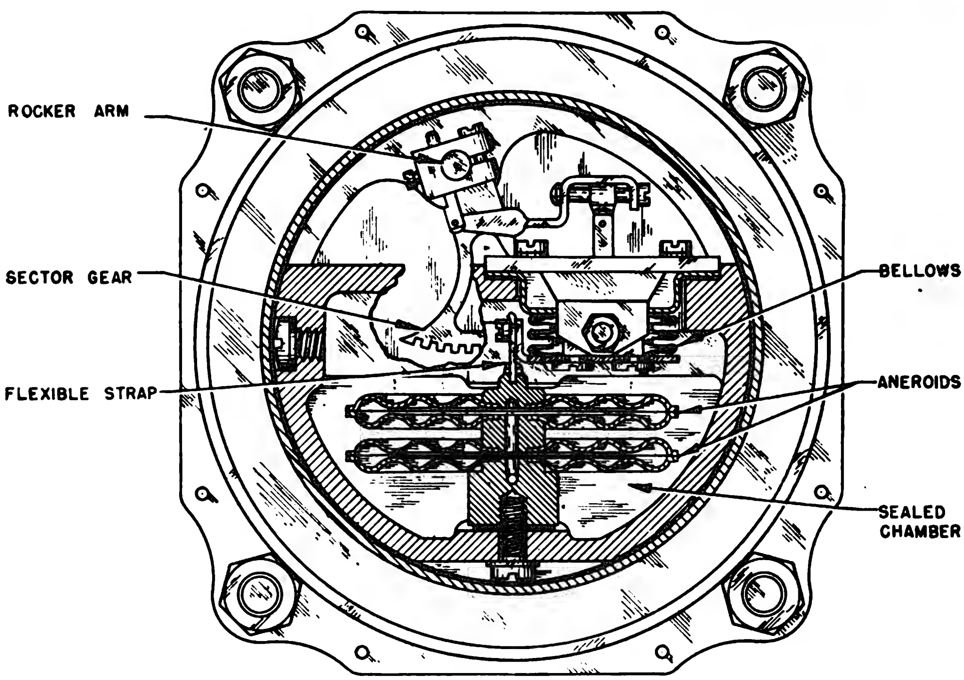


Figure 21. Internally sealed type of manifold-pressure gauge.

a damping tube at the rear of the case. The mechanical linkage used to transmit the motion of the diaphragm to the pointer is completely external to the pressure chamber and is therefore not exposed to the corrosive vapors of the manifold. The sealed chamber also prevents internal pressure reaching and damaging the cover glass and case. The aneroid assembly consists of two evacuated cells with a cell spacer between them. These are soldered and vented to a diaphragm base. An evacuation tube attached to the base provides a means of evacuating the cells. The two halves of the top cell are made of different materials, which introduces the necessary temperature compensation into the assembly. A flexible strap connects the aneroid assembly to a bellows. The bellows serves to transmit the motion of the aneroid, resulting from a change in manifold pressure, to the mechanical linkage without loss of pressure, thus acting as a pressure seal. Any movement of the linkage is transmitted to the pointer.

(4) Manifold-pressure gauges have scale ranges of 10 to 50 inches Hg. or 10 to 75 inches Hg. The tolerance is minus 0.4 inch Hg. The manifold-pressure gauge is designed to measure absolute pressure, and its operation is continuous. When the engine is inoperative, the gauge reading will depend upon the local barometric pressure, and under these conditions, functions the same as an ordinary barometer.

(5) Manifold-pressure gauge indications are governed by engine speeds and the type of supercharger employed. One kind of supercharger, the internal or geared type, is located in the induction system between the carburetor and the cylinder intake ports. External (exhaust-driven or turbo) superchargers deliver air, under pressure, to the carburetor. They are used with internal superchargers between the carburetor and the engine intake ports. In some cases, fuel injectors are used. In all types of fuel induction, the manifold-pressure gauge measures the pressure of the fuel-air mixture immediately before it enters the cylinder intake ports. A second gauge may be used on some airplanes to measure external supercharger pressure.

(6) A manifold-pressure gauge is really a barometer and therefore may be checked with the airplane altimeter by first setting the pointers of the altimeter at zero. The barometric scale should show the local pressure in inches of mercury, and the reading of the manifold pressure gauge should agree with this pressure within ±0.4 inch Hg. After the engine is started, the drain cock in the manifold-pressure gauge line, if used, should be opened for about 30 seconds, while the engine is idling. This will clear the line and gauge of any condensate that may have collected there. Drain cocks are required on all new installations. Trouble has been experienced with the remote indicating gauges due to condensate. When the drain cock is closed, the pointer should move to the left, since the manifold pressure will be low. As the throttle is advanced and the engine rpm increased, the pointer on the gauge should move to the right (clockwise).

(7) Manifold-pressure gauges, being directly connected to the manifold, are subject to sudden surges of high pressure. As a protection against these overpressures, a safety feature is incorporated in the gauge. This may be either a restriction screw or a dampening tube in the case-connection nipple. Proper setting of the restrictor is tested by applying a suction sufficient to bring the dial reading to 10 inches Hg. After release, the indicator should reach 25 inches Hg, with a lag of not less than 1 and not over 2 seconds. Similarly, after release from an applied pressure of 50 inches Hg, the indicator should reach 32 inches Hg, within the same limits.

f. Hydraulic-(Landing-gear) Pressure Gauge. (1) The landing-gear or hydraulic-pressure gauge (fig. 22) indicates the pressure available to

Figure 22. Hydraulic-pressure gauge.

operate the main landing wheels, tail-wheel flaps, brakes, bomb doors, and other hydraulic mechanisms. Depending upon the type of hydraulic system in use, the gauge may or may not function constantly during flight.

(2) A Bourdon-type mechanism is contained in the landing-gear pressure gauge. The pressure to be measured is admitted through a ¼-inch tube nipple at the back of the case. A vent in the bottom of the case admits atmospheric pressure and provides a drain for moisture. The scale of this gauge has a range of 0 to 2,000 or 0 to 3,000 pounds per square inch. Normal operating pressure ranges from 600 to 1,500 pounds per square inch. The tolerance at

zero, for this type of gauge, is ±40 pounds per square inch. The Bourdon tube and all connecting tubes have relatively heavy walls because high pressures are encountered.

g. De-icing Pressure Gauge. (1) In airplanes, on which various surfaces are "de-iced" by the alternate inflation and deflation of rubber "boots," the de-icing pressure gauge, shown in figure 23, gives the pilot an indication of the air pressure in the de-

Figure 23. De-icing-pressure gauge.

icing system. The gauge also provides a means of measurement in the setting of the relief valve in the de-icing pressure system.

(2) This gauge contains a Bourdon-tube mechanism. The pressure enters the tube through a connection at the back of the case. Atmospheric pressure is admitted through the vent at the bottom or rear of the case. The scale range of the instrument is from 0 to 20 pounds per square inch, and the tolerance is ±0.3 pounds per square inch. When the gauge is installed and connected to the de-icing system, the reading will remain zero at all times except when the de-icing system is operating. Because of the periodic inflation of the cells, the gauge reading will fluctuate from approximately 3½ to 7 pounds per square inch unless a leak in the system occurs. This fluctuation is not to be confused with pointer oscillation, which is not a normal condition in any airplane gauge and which, if present, must be corrected. The gauge is connected to the exhaust side of the vacuum pump (fig. 24) usually at the air filter.

7. Inspection and Maintenance

All pressure gauges must be checked at regular intervals for the following:

a. Luminosity of Dial and Pointer. The numerals, dial graduations, and pointers of pressure gauges are treated with luminous paint, so that they may read in the dark. If the paint becomes dull and discolored with age, or cracked and chipped from

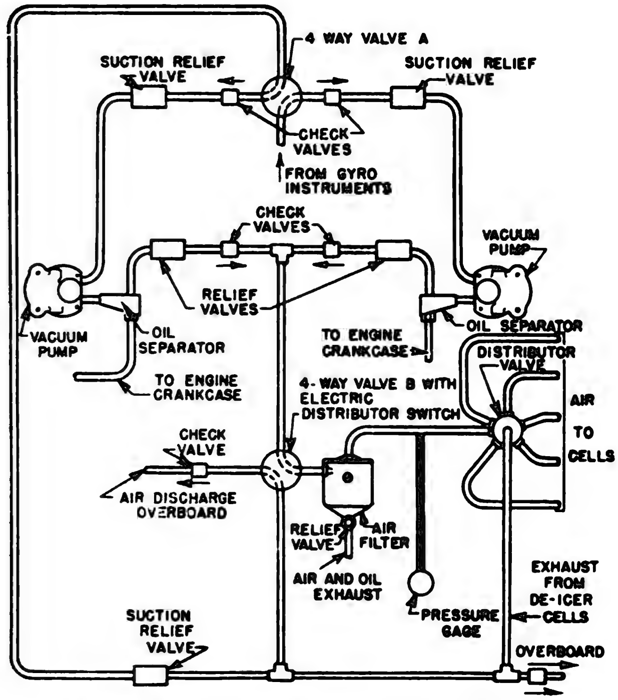


Figure 24. De-icing-pressure gauge installation.

normal vibration, the instrument is sent to the repair depot to be repainted and a serviceable instrument is installed in its place.

b. Correct and Clear Operation Markings. (1) Due to the wide divergence in operating pressures on various types of aircraft engines and aircraft equipment, it is necessary to paint or paste operating markings of various colors on the cover glasses of some of the instruments. Pressure gauges are marked to indicate the maximum permissible pressure and the normal operating range of pressure. Lines are marked on the cover glass, as shown in figures 8 and 15. Short radial lines (red) are used to indicate the maximum and minimum permissible pressure. Arcs of circles (green) are used to indicate the normal range of operating pressures. A short, white, radial index line is placed on the glass and case at the bottom of the instrument to make any movement of the glass apparent. Markers of the decalcomania transfer type, finished in luminescent materials for use with fluorescent lighting, are available and should be used for this purpose.

(2) It is necessary that the operating markings of various colors be clear and easily readable. The correctness of the markings can be easily determined by inspecting the short, radial, index line at the bottom of the instrument to see whether or not the cover glass has slipped. If the glass has slipped or is cracked, the instrument must be removed and replaced, since the markings have changed and dust

or dirt may have accumulated in the case. If the markings are not clear, they may be replaced by the crew chief.

c. SECURITY OF MOUNTING. The gauges must be mounted securely and all connecting lines anchored to prevent swinging or sagging.

d. ZERO TOLERANCE OF POINTER. Pressure-gauge pointers are checked for accuracy at zero. The tolerance should be within the limits specified for the particular gauge. An instrument, having a larger tolerance than specified, is removed for bench testing and is replaced by one which is more accurate.

e. SATISFACTORY LIGHT (IF APPLICABLE). The instrument light switch on the panel is turned on to determine whether the instrument lights are satisfactory. Before replacement of unsatisfactory lamps, the lamp resistor will be checked with a continuity tester. To determine satisfactory operation of fluorescent lamps, the inverter switch is turned on. Defective fluorescent lamps are replaced.

f. EXCESSIVE POINTER OSCILLATION. When pressure-gauge pointers fluctuate excessively, the dampening devices will be adjusted wherever applicable and all connections will be checked for proper security and anchorage. If the pointer still oscillates, the instrument is defective and will be replaced.

g. READINGS CONSISTENT WITH REQUIREMENTS. When the airplane engine is started, all pressure gauges will be checked for the proper operating pressures as designated by the Technical Orders for that particular airplane. At periodic intervals when the engine is not running, the manifold-pressure gauge is checked against the airplane altimeter and the station barometer. If the difference is more than that specified in Technical Orders, the manifold-pressure gauge will be removed and replaced. When the engine is running at idling speed (usually 600 to 800 rpm), the manifold-pressure gauge line in the cockpit will be opened for 30 seconds to remove condensed moisture, and the pointer will be checked for proper indication.

THERMOMETERS

8. General

a. In the operation of modern aircraft, much depends upon the operator's knowledge of the temperatures of engine units, engine fluids, and the surrounding air. To make these temperatures apparent visually, thermometers are provided. A thermometer is essentially an instrument which contains a substance having physical properties which vary with changing temperatures, and which measures and indicates the extent of these variations. That is, any change in temperature results in a change in the physical properties of the substance. The extent of this change is recorded on the calibrated scale of the thermometer in number of degrees. The physical properties thus utilized in thermometers are vapor pressure of gases, and the thermal expansion, electrical resistance, and electrical potential of metals.

b. The principles on which the operation of aircraft thermometers is based are:

(1) The variation of vapor pressure of volatile fluids caused by a change in temperature.

(2) The difference between the amount of expansion or contraction of two different metals caused by a change of temperature.

(3) The change of electrical resistance of a metal caused by a change of temperature.

(4) The change in electrical potential between two different metals caused by a change in temperature.

c. Thus, thermometers may be classified by principle of operation as:

(1) Vapor-pressure type.
(2) Bimetallic (thermal-expansion) type.
(3) Resistance type.
(4) Thermocouple type.

9. Principles of Operation

a. VAPOR-PRESSURE THERMOMETER. (1) The vapor-pressure thermometer (fig. 25) contains, in a closed bulb, a quantity of a liquid such as methyl chloride, which tends to evaporate or condense according to temperature changes. Within certain limits, the higher the temperature, the greater the amount of vaporization and the greater the vapor pressure exerted outward against the walls of the bulb; the lower the temperature, the greater the condensation and the lower the pressure on the bulb walls. Since the changes in pressure in the bulb depend on changes in temperature, these changes in temperature can be measured by connecting a pressure gauge, calibrated in degrees, to the bulb.

(2) To allow the vapor-pressure thermometer to indicate the temperature of some distant substance, the bulb containing methyl chloride is placed at the point where the temperature is to be measured, and a capillary tube conducts the pressure to a Bourdon-tube pressure gauge (fig. 26) on the instrument panel.

(3) The changes in vapor pressure of the methyl chloride in the bulb are not in exact proportion to the changes in temperature over the whole range of temperatures. Therefore, if the movable part of the Bourdon tube were free to move without guidance or restraint, the scale on which the pointer moved would have to be calibrated in nonuniform graduations. Since uniform graduation is desirable, either an eccentric cam or a "progressive restrainer" (fig. 27) is used to guide the motion of the tube. The restrainer consists of a number of adjusting screws which bear on part of the length of the tube and guide it through a certain range of its movement.

① *Indicator.* ② *Capillary.* ③ *Bulb.*

Figure 25. Vapor-pressure thermometer assembly.

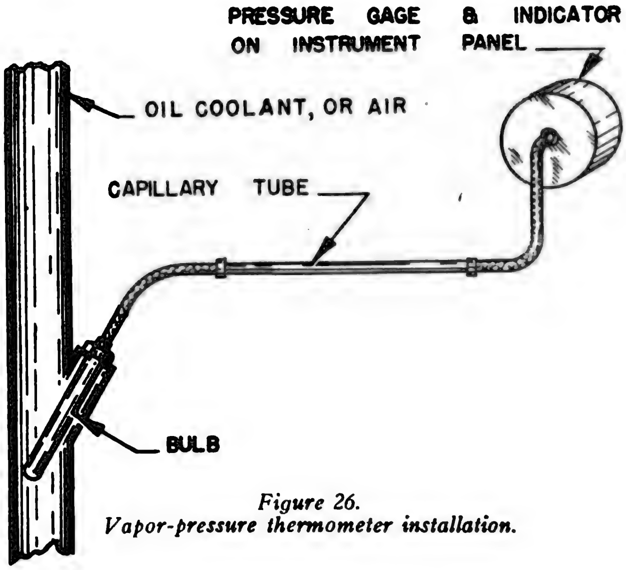


Figure 26.
Vapor-pressure thermometer installation.

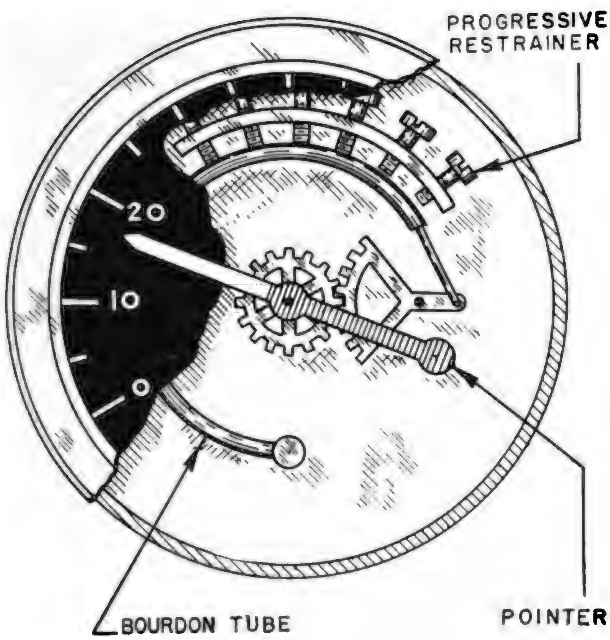


Figure 27. Progressive restrainer.

These screws must be adjusted from time to time so that the readings given by the pointer, according to the uniform scale on the indicator, will be accurate. This is accomplished at a depot.

b. Bimetallic Thermometer. Two metals, which expand different amounts with the same change of temperature, are used in the bimetallic thermometer. Assume that two thin strips of the two metals are brazed together and straightened out at normal temperature, as shown in figure 28①. If the metal *A* expands more than the metal *B* upon the application of heat, the bimetallic strip will tend to curl up, as shown in figure 28②. In aircraft

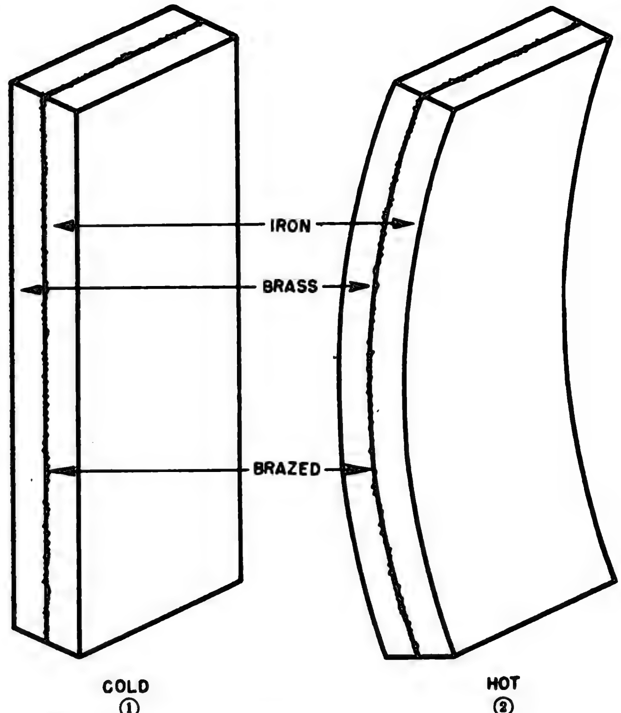


Figure 28. Effect of temperature changes on bi-metallic strip.

thermometers, the strip is coiled so that a change in temperature causes it to wind or unwind. A pointer attached to the coil, and moving with it, indicates the temperature on a suitable scale. (See fig. 29.) The principle advantage of this type thermometer is that it is very accurate.

c. Resistance Type Thermometer. (1) The electrical resistance of a metal is directly affected by temperature. The resistance of nickel wire, for example, increases as its temperature increases, so that a measure of the resistance of a piece of nickel wire is a measure of its temperature. An aircraft thermometer, of the resistance type, consists of a nickel element in a bulb (fig. 30) located where the temperature is to be measured, a resistance measuring device as the indicator, and the connecting leads. The resistance measuring device may be either a Wheatstone bridge and D'Arsonval mechanism or a ratiometer. The resistance bulb is connected either as one leg of the bridge in a Wheatstone-bridge thermometer (fig. 31) or in series with one of the rotor windings in a ratiometer thermometer (fig. 32.)

(2) A Wheatstone-bridge thermometer has a zero-adjusting screw on the face of the indicator and has a mechanical zero (a particular point on the dial where the pointer always comes to rest when the power supply is turned off.) (See fig. 33.) This point, clearly marked, may be 0°C. or any other

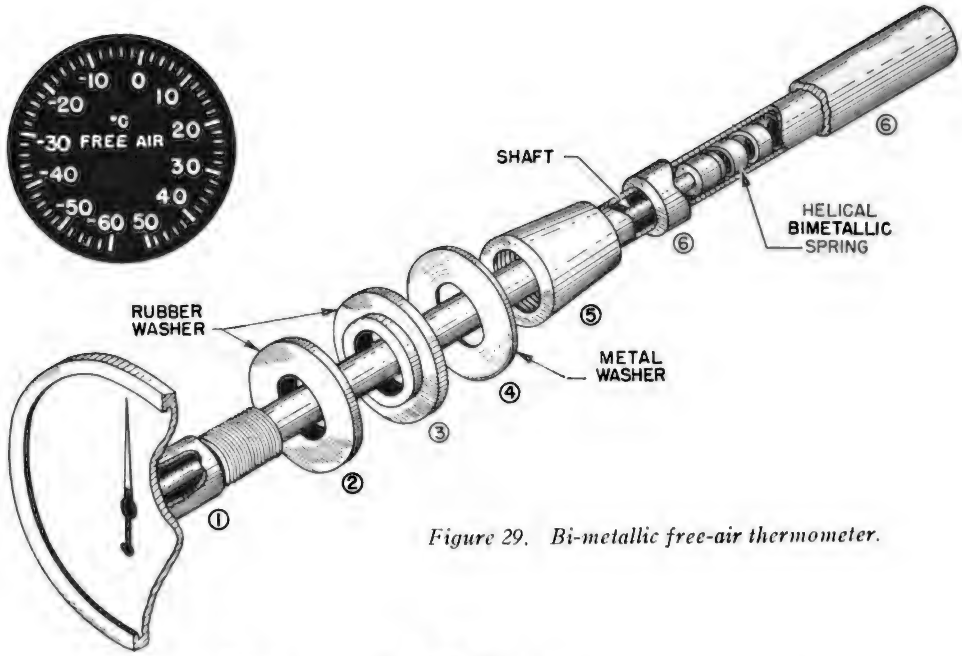
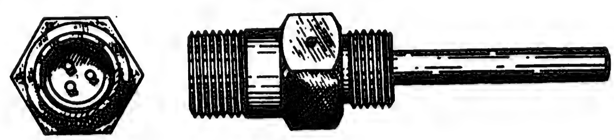
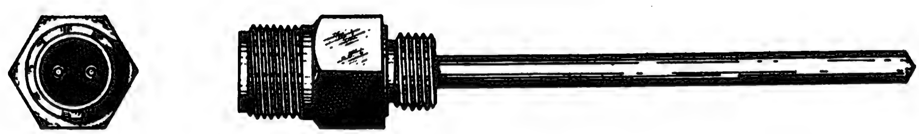


Figure 29. Bi-metallic free-air thermometer.



① *Short.*



② *Long.*

Figure 30. Resistance bulbs.

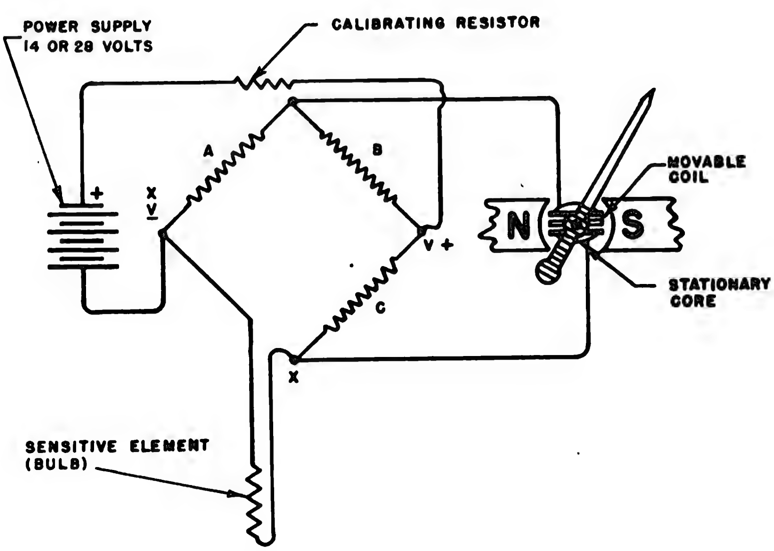


Figure 31. Wheatstone-bridge thermometer circuit.

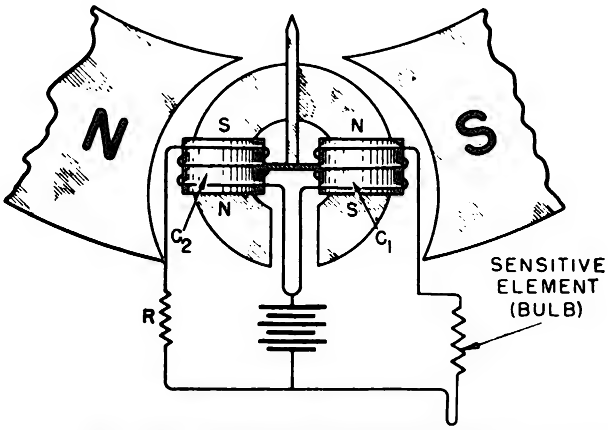


Figure 32. Ratiometer-thermometer circuit.

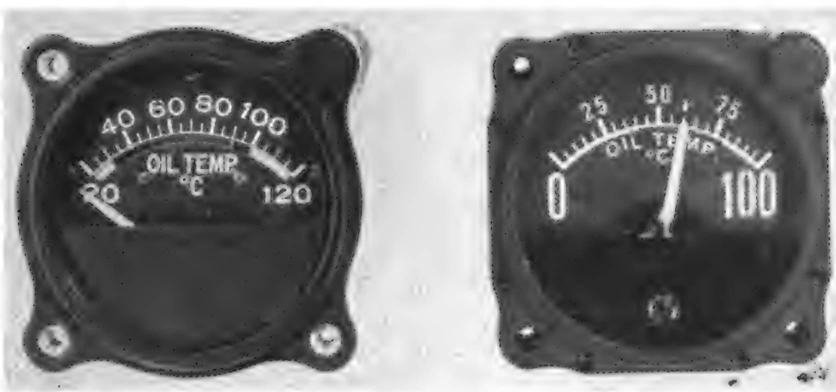


Figure 33. Wheatstone-bridge thermometer indicator.

point on the scale. In this thermometer, when the temperature of the sensitive element is 0° or 50°C. (depending on the design value), its resistance will be 100 ohms. Since the resistance arms *A, B* and *C,* shown in figure 31, have a fixed resistance of 100 ohms, the circuit will be in equilibrium and no current will flow through the coil of the D'Arsonval mechanism. When the bulb temperature increases or decreases, its resistance correspondingly increases or

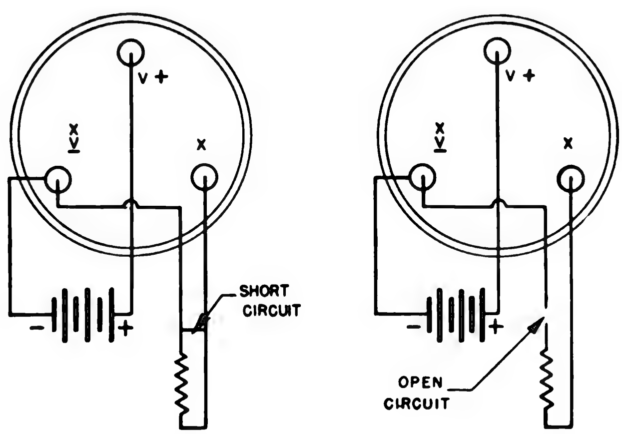


Figure 34. External wiring of Wheatstone-bridge thermometer, showing shorted and open leads.

decreases, while that of the other arms remains constant. The equilibrium is thus destroyed, and current flows through the coil of the D'Arsonval mechanism, causing it to rotate between the poles of the permanent magnet. Rotation of the coil causes movement of the pointer, indicating an increase of temperature when the bulb temperature (and resistance) rises, and a decrease when the bulb temperature (and resistance) decreases. The external wiring is shown in figure 34. Since the possible error due to variations of voltage supply is least near mechanical zero, the instrument is constructed so that mechanical zero is on that portion of the scale where the greatest accuracy is needed.

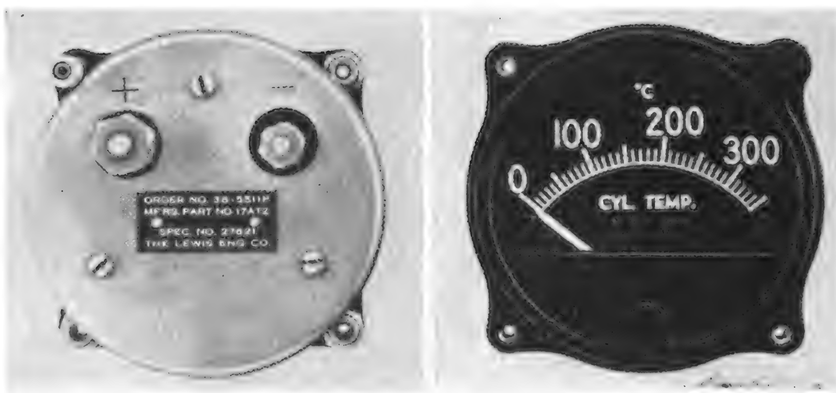
(3) The ratiometer type of resistance measuring device (fig. 35) is easily distinguishable from the

Figure 35. Ratiometer-thermometer indicator.

Wheatstone-bridge type because it has no external zero-adjusting screw. Its accuracy is affected very slightly by voltage variations. In this thermometer, the circuit has two parallel branches. (See fig. 32.) One has a fixed resistance in series with the coil C-2 and the other has the resistance bulb in series with the coil C-1. The two coils are wound around a rotor which is pivoted in the center. The pointer is attached to the rotor. A permanent magnet is so

placed that the air gaps between the magnet and the coils are larger at the bottom than at the top, providing an increasing, magnetic, flux density from bottom to top. The direction of current in each coil and the polarity of the magnate are such as to cause the coil carrying the greater current to move into the weaker field. When the bulb resistance equals the resistance R, and the same current is flowing through each coil, the torques balance and the pointer remains in the vertical (zero) position. When the bulb temperature rises, its resistance increases and the current through coil C-1 decreases. The torque of this coil decreases, and coil C-2 pushes downward into a weaker field, while coil C-1, with lower current, moves into a stronger field. The torques balance because the current-flux product, and consequently the force, of each coil is equal, at which point the coils will come to rest. Hence the pointer is moved to the new position on the scale which is calibrated in degrees of bulb temperature. This process is reversed if the bulb temperature decreases. Figure 36 shows the external wiring of the instrument.

d. Thermocouple Thermometer. (1) The purpose of the thermocouple type of thermometer is to measure relatively high (cylinder head) temperatures. Its operation depends on the difference between the electrical potentials of different metals in contact with each other. Two metals are used in aircraft thermometers of this type, either iron or copper being used with constantan which is an alloy of copper and nickel. The difference between the potentials of the two metals varies with the temperature, so that a measurement of this difference is an indication of the temperature of the contact or junction. Since the voltage difference is very slight, a very sensitive milli-voltmeter is needed to measure it. The milli-voltmeter employs a D'Arsonval mechanism which is essentially a current-measuring device, but since the amount of current which flows through the resistance of the mechanism is determined by the voltage applied, the D'Arsonval mechanism can and does serve as a sensitive milli-voltmeter, shown in figure 37. The pointer is attached to the movable coil of the D'Arsonval mechanism and moves with it.



① *Rear view.* ② *Front view.*

Figure 37. Cylinder-temperature gauge.

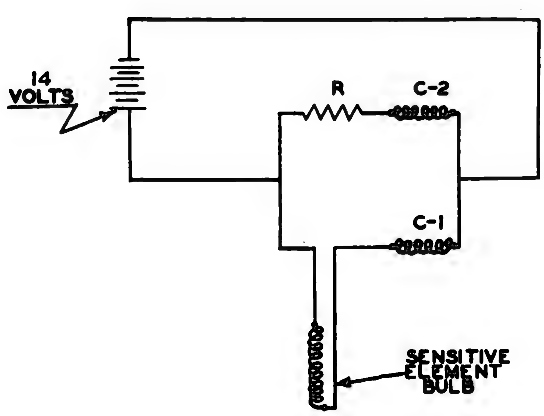


Figure 36. Ratiometer-thermometer wiring.

(2) Electrical contact is made between the two metals at the point where temperature is to be measured and at the indicator through the indicator windings. The two junctions are termed, respectively, the "hot" junction and the "cold" junction (See fig. 38.) The voltage available to cause electrical current to flow through the indicator depends upon the difference between the temperatures of the hot and cold junctions, and upon the compositions of the metals used. Since the cold junction is subjected to a wide range of temperatures, some compensation is necessary. This is provided automatically by a bimetallic spiral-spring compensator. This compensator sets the pointer to cockpit temperature if the thermocouple leads are disconnected.

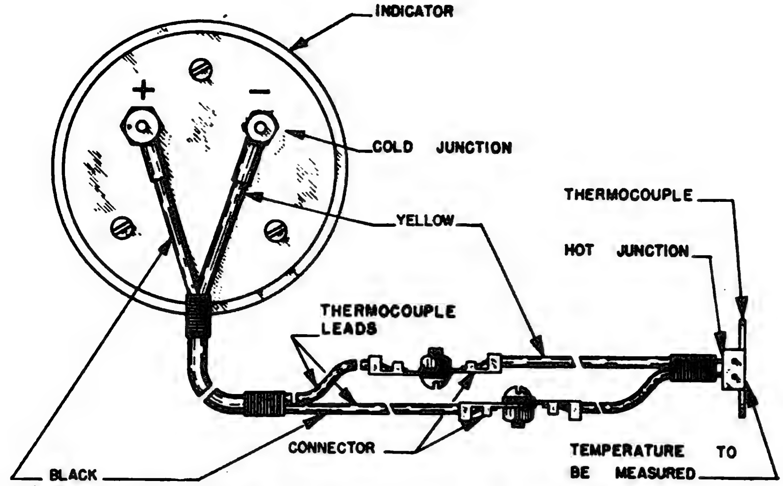


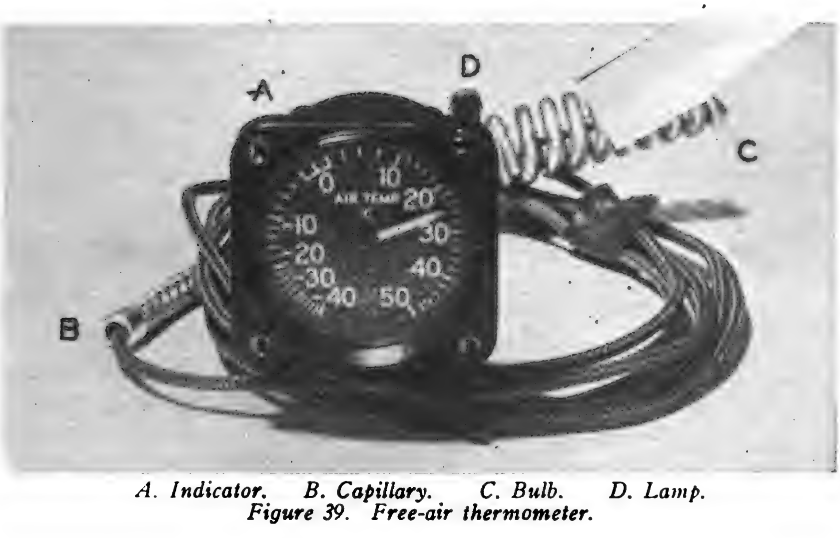
Figure 38. Diagram showing connection of cylinder-temperature indicator, thermocouple leads, and thermocouple.

10. Applications

a. Free Air Thermometers. (1) Outside temperatures are important in the general operation of the airplane, especially when the moisture content of the air is such that there is danger of ice forming on the lifting surfaces of the airplane. The purpose of free-air thermometers is to indicate these outside temperatures. Thermometers of this type are generally called "ice-warning indicators." Owing to the dependence placed on free-air thermometers in flight, they are very accurately built and calibrated and can be used at any time as master instruments to check thermometers on the airplane, provided that at the time of comparison, the bulbs of both thermometers can be expected to be at the same temperature. These thermometers are used also when it is necessary to take the temperature of the free-air surrounding the aircraft at various altitudes. With the aid of altitude temperature computers, the true altitude may be obtained when the indicated altitude is known. This is especially important when the airplane is performing a photographic or bombing mission, or where navigation problems, involving the use of airspeed, are to be solved.

(2) The instrument may be of the vapor-pressure type, the bimetallic type, or the resistance type. The range may vary, but it is generally from —50° to +50°C. The scale, shown in figure 39, may have marked, on either side of zero, a critical range where ice formations may occur. The bulb is generally installed outside the slipstream on the leading edge of the wing (or some other suitable location) and in a fore-and-aft position to minimize air resistance. The bimetallic thermometer, however, is mo[illegible] through a hole in the plexiglas, the exac[illegible] [illegible]n depending on the type of airplane.

b. Coolant Thermometers. [illegible] [illegible]ssist the pilot in operating the engine [illegible] temperature



A. Indicator. B. Capillary. C. Bulb. D. Lamp.
Figure 39. Free-air thermometer.

range in which best efficiency is obtained, coolant thermometers (fig. 40) or cylinder-head temperature gauges are used. Liquid-cooled engines usually operate at temperatures between 60° and 125°C. To prevent rapid loss of cooling liquid, the temperatures should always be held below the boiling point. While the boiling point of ethylene glycol is about 192°C. at sea level, it is only about 175°C. at 20,000 feet altitude; consequently at that altitude, the engine must be operated at a correspondingly lower temperature. Shutters on the radiator enable the pilot to control the temperature during normal operation. Coolant thermometers will warn the pilot of engine overheating. Overheating is the first indication of certain engine troubles and, if noticed in time by the pilot, the airplane may be landed with power before complete engine failure occurs. During the warming up on the ground, the coolant thermometer will also inform the pilot or mechanic when the engine has warmed up sufficiently for take-off and flight. In general, the cooling-liquid temperature should reach at least 70°C. before the take-off is attempted.

① *Single indicator.*

② *Dual indicator.*

Figure 40. Coolant thermometer.

(2) The mechanism may be of the vapor-pressure type or the electrical-resistance type, and frequently has a scale range of from +20°C. to +150°C. A thermometer well is incorporated in the coolant outlet line from the engine to the radiator. The thermometer bulb is installed in the well, and the outlet temperature of the coolant is indicated on the thermometer gauge in the cockpit.

(3) Another type of coolant-temperature indicating system, the self-synchronous remote-reading type, is described in section VII.

c. Cylinder-head Temperature Gauges. The function of the cylinder-head temperature gauge is to measure and indicate the temperature of air-cooled engines at some point on one of the cylinders, usually the hottest cylinder. The gauge is a thermocouple thermometer. The indicator has a scale range (fig. 41) of from 0° to 350°C. The thermocouple gasket of solid copper is usually installed beneath the rear spark plug of the hottest cylinder. The two leads, of iron and constantan or copper and constantan, are brazed to the copper gasket at the "hot" junction and attached to the indicator windings at the "cold" junction.

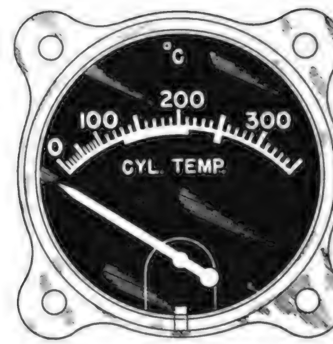


Figure 41. Cylinder-head-temperature gauge.

Note. The type and resistance of the leads to be used with an indicator are stamped or stenciled on the back plate of the indicator.

Where an adjustable resistor is not provided, the thermocouple leads must not be lengthened or shortened, since they are of a definite resistance and enter into the calibration of the instrument. Where an adjustable resistor is provided in the circuit, sections of the lead may be replaced and small variations in the length may be compensated for by adjusting the resistor until the total lead resistance is equal to that stamped on the back of the indicator.

d. Oil Thermometer. (1) During warm-up the oil thermometer (fig. 42) indicates whether the engine oil has reached a temperature sufficient for take-off. In general, the oil temperature should reach 30°C. before take-off is attempted. In flight, the oil thermometer indicates to the pilot whether or not the oil temperature is becoming excessive. The high

Figure 42. Oil-temperature gauge.

temperature of the various engine parts tends to heat and thin out the lubricant (lower its viscosity) and hence decrease its lubricating qualities. The oil is cooled externally by an oil radiator with shutters which may be controlled by the pilot from the cockpit.

(2) The mechanism of this thermometer may be of the vapor-pressure type or the electrical-resistance type, and may have a scale range of from 0° to 150°C. The thermometer bulb is connected in the oil line near the inlet to the engine, facing the direct flow of the liquid.

(3) The self-synchronous remote-reading oil-temperature gauge is described in section VII.

e. CARBURETOR-MIXTURE AND AIR THERMOMETERS. To indicate the temperature of the fuel-air mixture at the carburetor, the carburetor-mixture thermometer is used. The carburetor-air thermometer indicates the temperature of the air entering the carburetor. Dual indicators for either carburetor-mixture indications or carburetor-air indications are available with a changeable caption, in the form of a subscale, carrying the words "Air" and "Mixt.", either of which can be exposed to make the caption read "Carb. Temp. Air" or "Carb. Temp. Mixt." (See fig. 43.)

Figure 43. Carburetor-mixture thermometer indicator.

(1) Either thermometer may be of the vapor-pressure or the electrical-resistance type, and usually has a scale range of from —45° or —100° to +50°C. The bulb is generally installed in the throat of the carburetor (mixture chamber). When the instrument is being used as a carburetor-air thermometer, the bulb is installed in the air inlet to the carburetor.

(2) The self-synchronous remote-reading type of carburetor air- or mixture-temperature indicating system is described in section VII.

f. UNIVERSAL ELECTRICAL THERMOMETER. The purpose of the universal electrical thermometer, which has a conventional ratiometer mechanism and a standard scale range from —70°C. to +150°C., is to indicate the temperature of any medium with which a sensitive element (resistance bulb) is in contact. It is used on aircraft to indicate the temperature of the free air, carburetor air or mixture, engine cooling liquid, or the lubricating oil entering the engine. Each thermometer indicator is identified by a plate supplied for that purpose or by a label painted with aircraft enamel, which states the specific use.

11. Inspection and Maintenance

a. Some of the inspections and maintenance procedures are common to all thermometers; each particular type of thermometer also requires specific inspection and maintenance procedures. These are given in the following paragraphs.

b. ALL TYPES. (1) Because of the wide range of operating temperatures, it is necessary to have clear and correct operation markings of proper colors on the cover glass to indicate the operating limits of the instrument. Correctness of markings can be determined by noting if the cover glass has slipped. If the glass has slipped or cracked, the instrument must be replaced, because the markings have changed position, and dust, dirt, or moisture may have accumulated within the case. If the markings are not clear, they may be replaced by the crew chief.

(2) Inspect the illuminating lamps or luminous markings for condition.

(3) Check for loose dials or pointers. Excessive oscillation of the pointer may be due to looseness.

(4) Check the entire installation for security of mounting.

c. VAPOR-PRESSURE TYPE. (1) The units of vapor-pressure thermometers are sealed and cannot be separated without a total loss of the assembly. Particular care is to be taken of the capillary tubings, which should not be cut, broken, dented, stretched, or pulled taut, since this damages the thermometer beyond economical repair. They should

be checked for minimum radius of bend, worn armor at all friction points, flexibility, and anchorage. If the correct lengths are not available, replacements may be made with longer capillary tubing provided the excess is neatly coiled and taped to some structural part of the fuselage.

(2) Excessive friction in the indicating mechanism will result in wrong readings or sluggish operation. Tap the instrument sharply and note whether the pointer assumes the correct reading. If the pointer does not correct itself, it may be due to corrosion of the mechanism. The thermometer should be replaced.

(3) When the vapor-pressure thermometer is used as a free-air thermometer, the bulb is checked for alignment. If the bulb is out of alignment it must be realigned for proper operation of the instrument. The free-air thermometer is checked against the hangar thermometer, or any other master thermometer, for similarity of reading. Since the free-air thermometer must be exact and therefore has no tolerance, these readings must coincide. If they do not, the thermometer will have to be replaced with an accurate instrument.

(4) Loss of either liquid or vapor methyl chloride from the system will make the system inoperative; hence the system must be protected against damage. The capillary tubing should not be placed near heated parts of the engine, nor should there be any bend having a radius of less than 1½ inch. The capillary tube should be securely fastened throughout its length so that it cannot whip or chafe, and yet it must be loose enough to allow for vibration of the engine. Excess tubing should be neatly coiled and fastened securely to a convenient part of the aircraft where it will be out of the way. When the instrument is moved, care should be taken to mark the points where the capillary is anchored, in order that a satisfactory reinstallation may be made.

d. Bimetallic Type. The bimetallic free-air thermometer is checked against a master liquid-in-glass thermometer for similarity of reading. Since the free-air thermometer must be exact, its accuracy must be within the values given in Technical Orders. If not, the thermometer will have to be replaced with an accurate instrument.

e. Resistance Type. (1) Before condemning or reporting either the indicator or bulb as being unserviceable, a careful check should be made to insure that the apparent failure is not due to loose or shorted electrical connections, especially at the bulb end. The leads must be checked for proper insulation, anchorage, and security of connection at all terminals, and replaced if found unsatisfactory.

(2) To check the thermometer for accuracy at mechanical zero, interrupt the current supply to the instrument. The Wheatstone-bridge type indicator can be adjusted for zero by means of the small screw on the front of the instrument. The ratiometer type indicator has no zero adjustment screw. The normal position of the pointer, with no voltage applied, is off scale at the low temperature end of the scale. An instrument, having a larger error than permissible, is removed for bench-testing and replaced by one which is accurate.

(3) Should a lower reading than normal occur, a short circuit in the resistance bulb or the leads is indicated, since a short circuit will lower the resistance and the instrument indication. A complete short will result in the lowest instrument reading. Another possible trouble is an open circuit in the bulb or leads, due to an accidental break in the leads or resistance wire of the bulb. The result is high resistance, such as would be caused by an extremely high temperature. The reading will therefore be extremely high. Replacement of the bulb or leads will be required if either of these troubles occurs. Faulty indications may also be attributed to a defective indicator.

f. Thermocouple Type. To check the thermocouple (cylinder-head) thermometer for its zero position, disconnect one of the leads from a stud on the back of the indicator. The instrument should then indicate the temperature of the cockpit. This can be checked by placing a master mercurial thermometer beside the cylinder-temperature gauge and allowing sufficient time for the master thermometer to attain cockpit temperature. If the cylinder-temperature gauge does not agree, it can be adjusted to agree with the master-thermometer reading by means of the zero adjusting screw located on the front of the instrument.

g. Indication of Proper Engine Operation. With the engines operating, the thermometers should indicate the various temperatures accurately at different speeds and without excessive pointer fluctuations. The readings for ground throttle, cruising speed, and full throttle should be consistent with the requirements, as designated by the "G" file for the particular airplane. These readings on accurate thermometers indicate continually to the pilot whether the engine is operating properly during the various operating conditions.

SECTION IV
TACHOMETERS AND SYNCHRONISM INDICATORS

12. General

a. In modern airplanes, tachometer indicators, which tell the speeds of the engines, are of particular importance. This type of instrument is given a conspicuous place on the panel because of the importance of engine speed as an indication of performance. Internal combustion engines operate most efficiently over a very narrow range of speeds.

b. Tachometers are generally classified as follows:

(1) Chronometric.
(2) D-c generator-voltmeter.
(3) A-c generator-voltmeter.
(4) Synchronous rotor.
(5) Self-synchronous (autosyn). (See sec. VII.)

13. Chronometric Tachometer

a. GENERAL. (1) In some airplanes the pilot's seat is near enough to the engine to permit engine speed to be measured mechanically. This is accomplished, as in an automobile, by a flexible shaft which connects the engine with a chronometric tachometer. (See fig. 44.) The tachometer is mounted in the cockpit for the convenience of the pilot.

(2) The chronometric tachometer is shaft-driven and used only on single-engine airplanes. Unsatisfactory operation results when the shaft length exceeds 20 feet. Attempts to use shaft-driven tachometers with a special two-way adapter on two-cockpit airplanes in which two complete sets of engine instruments were installed did not prove satisfactory. The bends in the shafts were so sharp that they caused wear and friction, resulting in quick deterioration of the shaft.

b. DESCRIPTION. (1) The chronometric tachometer driveshaft is driven from a tachometer drive at half the speed of the engine crankshaft. The indicator dial, shown in figure 45, is graduated to

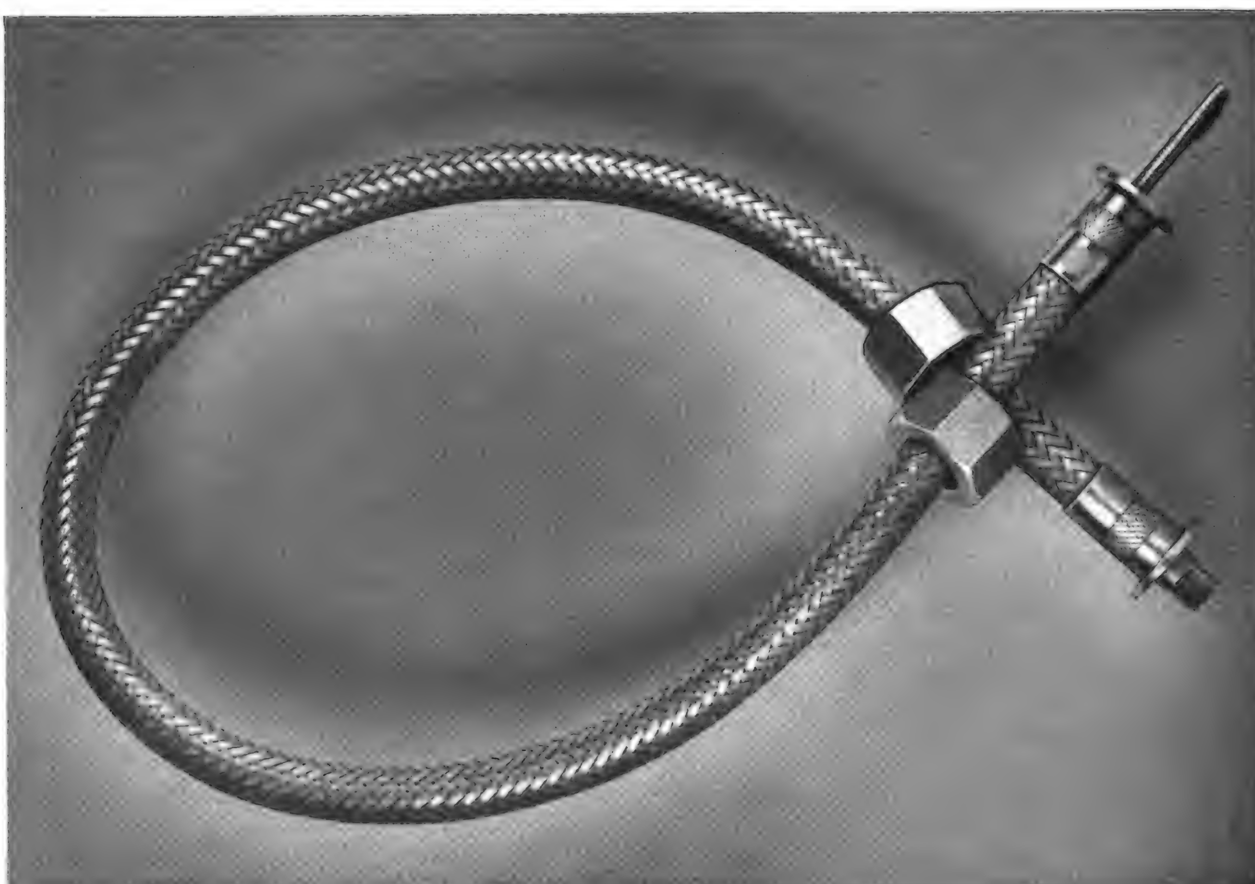


Figure 44. Chronometric-tachometer drive shaft.

Figure 45. Chronometric-tachometer indicator.

read in rpm of crankshaft speed. The indicator totals the number of revolutions during an interval of time and indicates that rate of engine speed during the following interval. This mode of operation causes the pointer to move by jerks. As long as the driveshaft continues to rotate, this cycle of operation continues automatically. After rotation of the driveshaft ceases, the clock mechanism continues to tick for at least 5 seconds and the indicator hand returns to zero in a series of jumps.

(2) Standard types of chronometric tachometers usually have a range of 0 to 3,500 or 0 to 4,500 rpm. Each type is designed to include reversing mechanism, which permits it to be driven clockwise or counterclockwise, so that no damage will be done to the mechanism because of engine kick-back.

(3) The driveshaft assembly consists of a shaft, which is made of hard-drawn, bronze, wire shaped in a coil with suitable tangs soldered to each end for attachment to the engine and the instrument. The shaft is placed in a braided-copper, covered, metal casing which serves as a bearing in which the shaft can rotate. All parts are nonmagnetic, so that they will not interfere with compasses, and the covering on the casing serves as a shield to prevent interference with the radio.

c. INSTALLATION. (1) The chronometric tachometer is mounted on the instrument panel in such a manner as to permit the shortest, most direct flexible-shaft connection.

(2) The permissible minimum radius of bend in the shaft is 6 inches. When sharp bends at the engine or instrument end of the shaft cannot be avoided in any other way, 90° adapters may be used.

(3) The shaft should be anchored at frequent intervals to prevent swinging and sagging. Flexible shafts should be located where excessive heat will not reach them.

(4) The driveshaft retaining washer is placed on the engine end of the shaft to assist in holding the shaft in the casing during handling procedures prior to installation of the shaft assembly and is not of material value to the assembly after it has been installed. Therefore, if a replacement washer is not available, it may be left off the shaft entirely.

d. INSPECTION AND MAINTENANCE. (1) If the pointer acts erratically, the fault will often be found in the flexible driveshaft. It may be due to a whipping of the shaft inside the housing, caused by a bend of too-short radius, by a dry flexible shaft, or by shaft connections which are either worn or of improper size.

(2) If the instrument fails to indicate, faulty connections or a broken cable may be the cause. Care must be exercised in connecting the flexible shaft, since the cable is easily broken. If the shaft becomes defective, it is not repaired but is replaced with a new one.

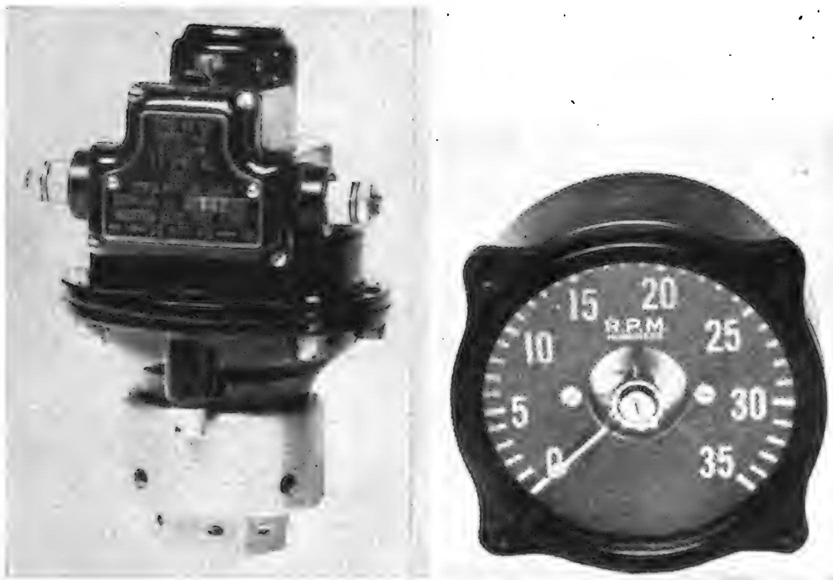
(3) The inspection and lubrication of tachometer shafts will be accomplished at each engine change unless local conditions warrant more frequent lubrication. Disassembly of the tachometer shaft is accomplished by disconnecting both ends of the shaft, removing the washer at the engine end, and pulling the inner shaft out of the casing from the instrument end. Both the inner shaft and the casing will be inspected for wear and corrosion and replaced with a complete assembly if either part is found to be excessively worn. The shaft is lubricated with a light coat of low-temperature grease, AN aeronautical specification AN-G-3, prior to re-installation in the casing.

14. D-C Generator-Voltmeter Tachometer and Synchronism Indicator

a. GENERAL. In large modern airplanes the chronometric tachometer failed primarily because of the weaknesses of long flexible shafts due to an excessive amount of bending. The distance between airplane engines and the instrument panel became so great that rotating mechanical connections were impractical. Consequently the d-c (direct-current) generator-voltmeter tachometer system was produced. This made it possible to include in the system a synchronism indicator, which, when connected to two d-c (direct-current) generator-voltmeter tachometers through the proper circuit, indicates the difference between the rpm of two aircraft engines. Since synchronization of two engines by ear alone or by reading two tachometer indicators is difficult,

the synchronism indicator allows the pilot to adjust the throttles and mixture controls so that both engines will operate at the same speed. This procedure minimizes vibration and increases engine efficiency.

b. DESCRIPTION. (1) The d-c generator-voltmeter tachometer (fig. 46) is an electrical instrument composed of a d-c generator, a voltmeter used as an indicator, and connecting leads. The generator, geared to the engine crankshaft, turns at one-half crankshaft speed. Since it is connected electrically to the voltmeter, an instantaneous reading is obtained. As the engine speed increases or decreases, the resulting reading on the indicator varies because the actual voltage output of the generator is directly proportional to the engine speed. The synchronism indicator (fig. 47) is connected into the circuits with the tachometer indicators and generators. In construction, it is essentially a very sensitive voltmeter, which is adjusted to measure any difference between the voltages generated by the two generators. A control switch makes it possible to measure either engine rpm. ("Tachometers On" position of switch) or difference between engine rpm. ("Synchronizer On" position of switch.)



① *Generator.* ② *Indicator.*

Figure 46. D-c tachometer indicator and generator.

(2) The scale range of the tachometer indicator is 0 to 3,500 rpm. The case is provided with a shield to prevent magnetic interference and keep static from interfering with radio operation. Three terminals protrude through the rear of the case for connecting the indicator in the circuit. These are marked +, *1*, and *2*.

(3) The tachometer generator is a small, compact unit designed for easy attachment to the engine accessory section. The armature shaft is mounted in ball bearings and provided with a tang for insertion into the drive unit on the engine. The rotation direction of the generator is optional and will be governed by the particular type of engine to which it is attached. If the direction of rotation is clockwise, the right-hand terminal will be positive; if the direction of rotation is counterclockwise, the left-hand terminal will be positive.

Figure 47. D-c synchronism indicator.

(4) The synchronism indicator scale (fig. 47) has the zero mark in the center and a range of 50 rpm on either side of zero. The instrument case is shielded to reduce magnetic interference with compasses and radio equipment. Two terminals marked + and —, for connecting the indicator into the circuit, protrude through the rear of the case. The + terminal must be connected to the + terminal of the right engine tachometer.

c. Operation. (1) The switch is first set visually for the "Tachometers On" position, so that the engine speeds will show on each individual tachometer indicator. When the desired altitude has been attained and the airplane has been "trimmed", the switch is set for the "Synchronizer On" position. The instrument will then indicate, by means of the difference between the generated voltages of the two tachometer generators, the difference in rpm between the speeds of the two engines. A clockwise pointer movement indicates that the right engine is running at a greater speed, and a counterclockwise rotation indicates that the speed of the left engine is greater. If the throttles are adjusted until both engines are running at the same speed, the indicator pointer will remain at zero. After both engines are synchronized, the position of the switch is optional.

(2) Simultaneous indication of the tachometers and synchronism indicator is not possible. It is necessary to select either one or the other, and no damage will result from continuous or intermittent operation on either of the elective positions of the switch.

d. Installation. (1) When the generator is mounted, the threads on the tachometer-drive outlet on the engine and threads on the generator are cleaned and a drop of oil applied. The generator is then fastened to the tachometer-drive outlet on the engine; the unit may be mounted with the terminal studs in any direction convenient for installation. The indicator is connected to the generator, as shown in figure 48, with the correct size wire.

(2) Two tachometer indicators may be used in a single-engine airplane where a complete set of engine instruments is required in each of the two cockpits. The two indicators are connected to a single generator, as shown in figure 49.

(3) When the synchronism indicator is installed on an airplane having two or more engines, it is

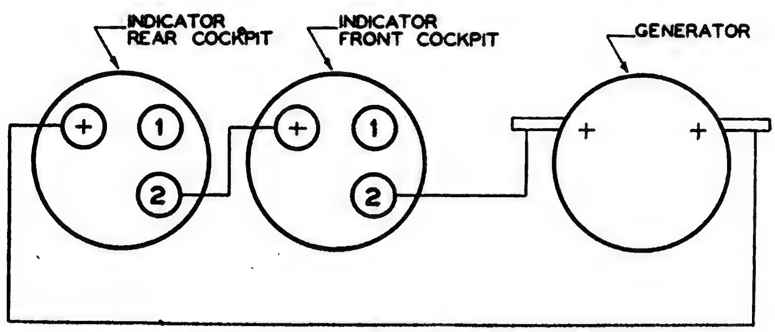


Figure 49. D-c tachometer wiring diagram (two indicators).

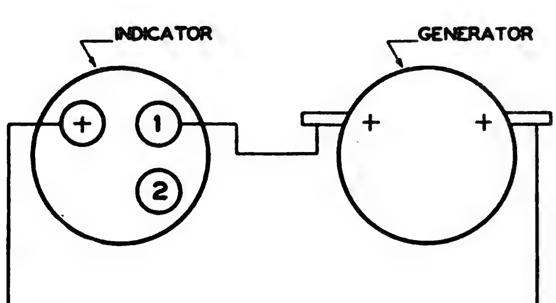


Figure 48. D-c tachometer wiring diagram (one indicator).

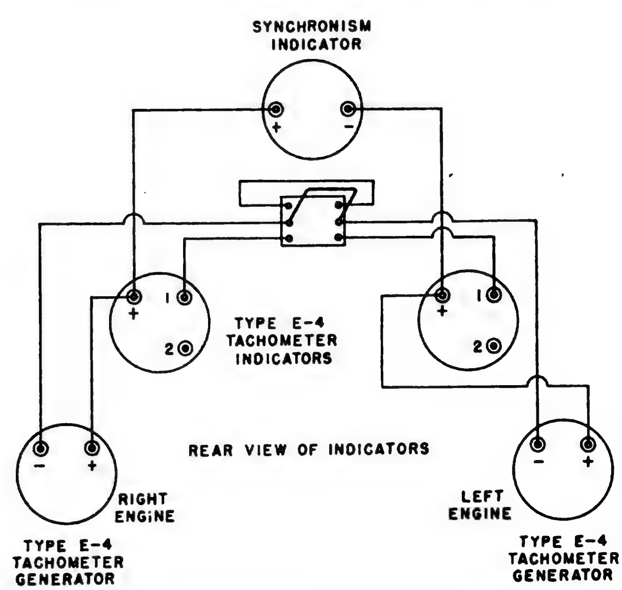


Figure 50. Wiring diagram of D-C tachometer and synchronism indicator.

mounted on the instrument panel and connected to each tachometer circuit, as shown in figure 50.

e. Inspection and Maintenance. If the tachometer indicator reads backwards when the engine is started, reverse the connections at the generator. The indicator and generator are sealed units, and any repairs or adjustments necessary to the internal mechanisms are major repairs. The leads must be of the specified gauge and long enough to prevent tautness at any point.
Installation of the leads must be unbroken at all points, and the leads must be anchored to structural members of the airplane at least every 18 inches. All connections should be clean and tight; otherwise resistance will be introduced and the readings will be incorrect.

15. A-C Generator-Voltmeter Tachometer

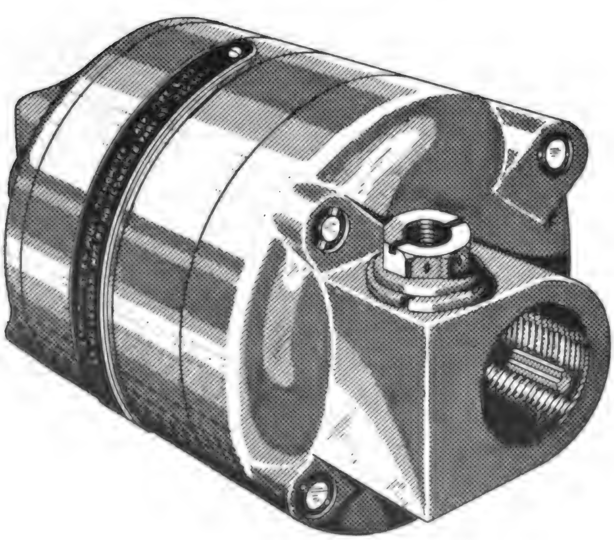
a. General. The purpose and use of the a-c (alternating-current) generator-voltmeter tachometer are identical with those of the d-c type. The advantage of the a-c tachometer is that there are no brushes to cause error or radio interference. The troubles, caused by the effect of dirt, oil, wear, and vibration upon the brushes, are thus avoided.

b. Description. The tachometer consists of an a-c generator, a voltmeter used as an indicator (fig. 51) and connecting leads. The generator consists of a permanent-magnet rotor revolving within a stator winding. The indicator consists of a d-c voltmeter and a rectifier unit.

c. Operation. Rotation of the permanent-magnet rotor in the generator sets up an a-c voltage in the stator windings. This voltage is transmitted to the indicator by connecting leads. The a-c voltage is converted to d-c voltage by the rectifier unit and measured by the d-c voltmeter indicator.

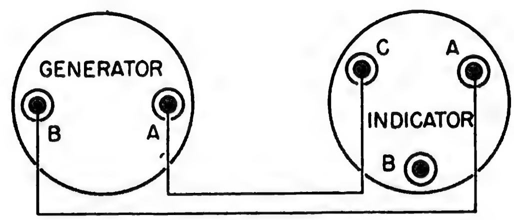
d. Installation. The tachometer generator is mounted on the tachometer drive of the engine. Connection is made between generator and indicator (fig. 52) by the correct size wire soldered to the removable AN standard plugs.

① *Indicator.*

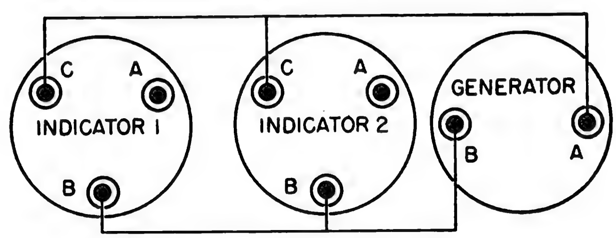


② *Generator.*

Figure 51. A-c generator-voltmeter tachometer indicator.



① *One indicator.*



② *Two indicators.*

Figure 52. A-c tachometer wiring diagram.

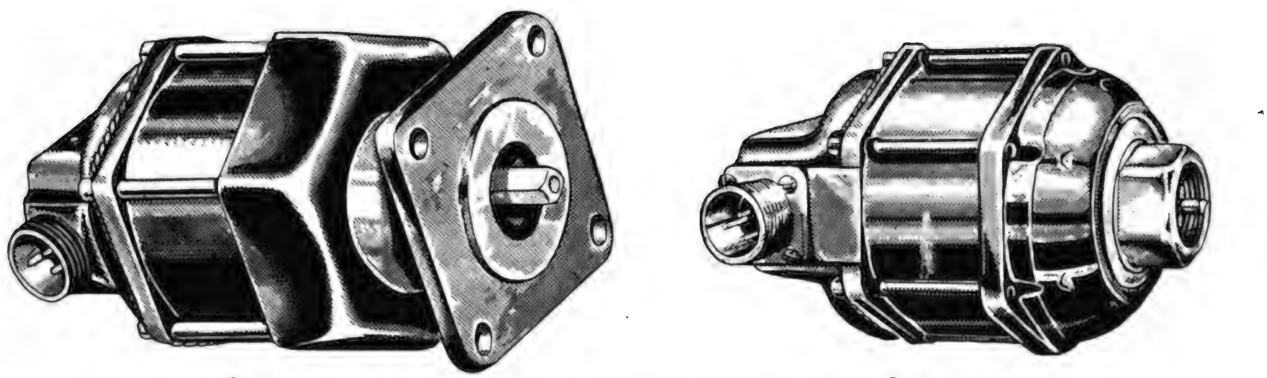
e. Inspection and Maintenance. The generator and indicator units of this tachometer are sealed units, and any repairs or adjustments necessary to the internal mechanisms are major repairs. Zero adjustment by means of the screw on the face of the indicator is made only at the time of calibration and is not a part of line maintenance. The leads at all terminals must make good, clean contacts, and insulation of the leads must be unbroken at all points.

16. Synchronous-Rotor Tachometer and Synchronism Indicator

a. General. The synchronous-rotor tachometer is designed for the same purpose as other electrical tachometers, but has certain definite advantages. It is very accurate throughout the normal operating range. It employs no brushes, commutators, or slip rings which may involve excessive error, frequent maintenance, or radio interference. Where an aid to synchronization is desired, a synchronism indicator may be used with two or more synchronous-rotor tachometers.

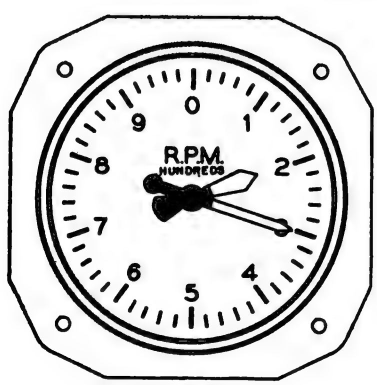
b. Description. (1) A synchronous tachometer is made up of the following: a three-phase electrical generator (fig. 53) containing a rotor which is turned by the tachometer drive of the engine; connecting electrical leads; an indicator (fig. 54). A rotor in the indicator turns at a speed proportional to the speed of the rotor in the governor. The indicator moves the indicating-pointer system through a gear train (using the magnetic-drag principle.)

(2) The generator rotor is driven from the tachometer-drive outlet in the engine accessory section

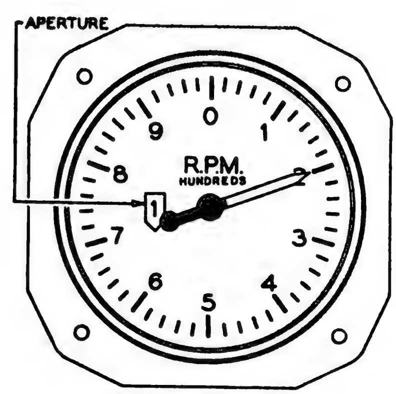


① *Screw mount.* ② *Pad mount.*

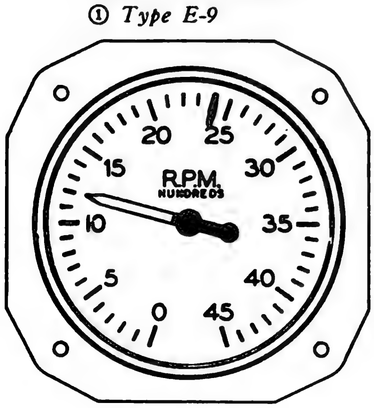
Figure 53. Generator-voltimeter tachometer generators.



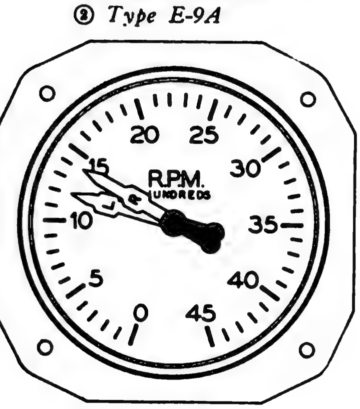
① *Type E-9*



② *Type E-9A*



③ *Type E-13*



④ *Type E-14*

Figure 54. Synchronous rotor tachometer indicators.

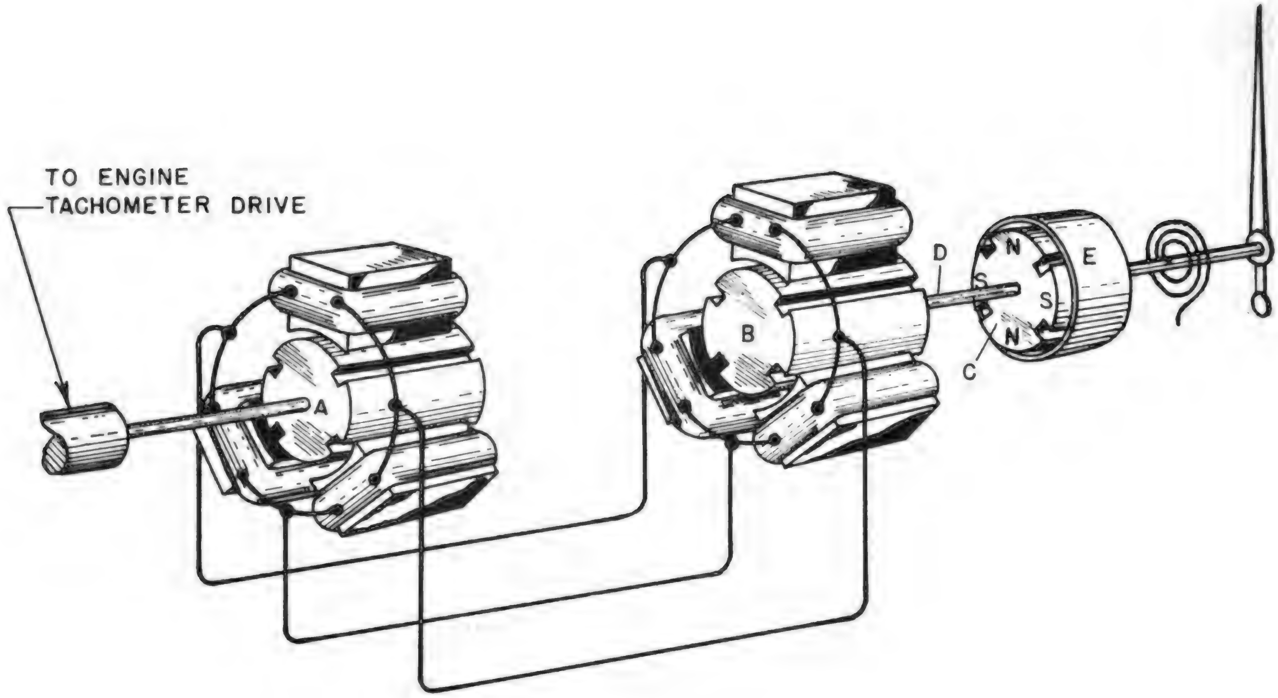


Figure 55. Synchronous-rotor tachometer.

at one-half the speed of the engine crankshaft. The rotor is a strongly magnetized permanent magnet *A*, (fig. 55), the magnetic field of which, cuts the stator windings and sets up alternating voltages between the generator terminals. These voltages are transmitted to the stationary windings of the indicator, causing a rotating magnetic field in synchronism with that of the generator field. The magnetic rotor *B* (fig. 55) of the indicator is dragged around by this rotating field and thus rotates at a speed proportional to the speed of the magnet *A* in the generator. Rotor *B* is connected to magnet *C* by the shaft *D* and turns at the same speed. The metal drum *E*, because of the current induced in it, is pulled around by the magnetic field of magnet *C* with a force proportional to the speed of the magnet. Rotation of the drum is restrained by a spring, so that the amount of rotation of the drum is proportional to the engine speed. The drum may move one or more pointers through a mechanical linkage.

(3) The dual-element tachometer consists of two identical elements, each of which in turn consists of a synchronous motor and an indicating element similar to that described in the preceding paragraph. In this indicator, the pointers are driven by the elements through gears on concentric shafts to which the pointers are attached. Although the elements of the dual-element indicator are similar to that of a single-element indicator, they are smaller in size so that two elements can be placed in the same space as that occupied by the single-element indicator. The dual-element tachometer permits the speeds of two engines to be indicated on a single instrument.

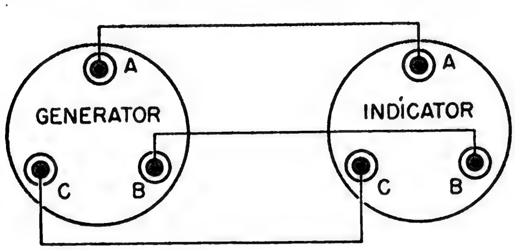
(4) Types of scales with which synchronous-rotor tachometers are equipped are shown in figure 54. The type E9 indicator has two pointers arranged concentrically, which indicate revolutions per minute on a common scale, the long pointer indicating the hundreds and the shorter one the thousands. (The long pointer in moving through the scale of the instrument makes 3½ revolutions per minute. The short pointer in moving through the range of the instrument makes 0.35 of a revolution.) The type E-9A indicator has only one pointer which reads in hundreds, the thousands being indicated by the number which appears in the aperture at the left. The type E-13 indicator shown, has only one pointer which reads in hundreds of revolutions per minute. The scale range is 0 to 4,500 rpm. Each subdivision on the scale represents 100 rpm. The type E-14 indicator shown is of the dual type. It has the same type scale as the type E-13 indicator, but has two pointers—one for the right-hand engine and one for the left-hand engine.

(5) For all but one engine of the airplane, the synchronism indicator employs induction motors with light weight rotors which are turned solely by induction. This eliminates the necessity of having

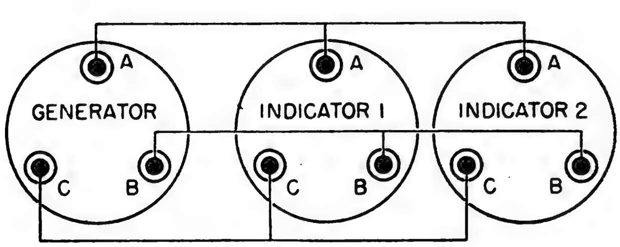
commutators, brushes, or other rubbing parts which impair accuracy and create radio interference. An indicator designed for a four-engine airplane would have three such motors. A miniature pointer is attached to each motor. These pointers are mounted on a dial which has no graduations, and each is numbered to indicate the engine to which it is connected.

(6) The direction and speed of rotation of a pointer indicates the relative speeds of that engine and the one selected as a "master." It is customary to select the outboard left engine as the "master." The tachometer generator of the "master" engine is wired to the rotors of the elements and the tachometer generators of the other engines are generally wired to the rotors of the elements in the synchronism indicator. If an engine is operating at a higher rpm than the master engine, the pointer will rotate clockwise. To synchronize the engines, the throttles of all but the "master" engine are adjusted until the pointers stand still.

(7) When a synchronism indicator is incorporated in the system, two systems of connection are used: the ungrounded (3-wire), shown in figure 56; and the grounded (2-wire), shown in figure 57. If the ungrounded (3-wire) system is used, the direction of indicator rotation may be changed by reversing the leads on any two terminals of the generator; if the grounded (2-wire) system is used, the direction of indicator rotation may be changed by reversing the *A* and *B* leads at the generator. Figure 58 shows the corresponding diagrams for a dual synchronous-rotor tachometer. Direction of indi-

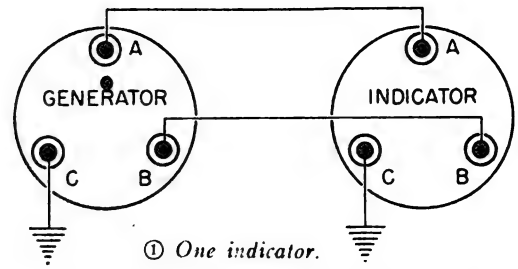


① *One indicator.*

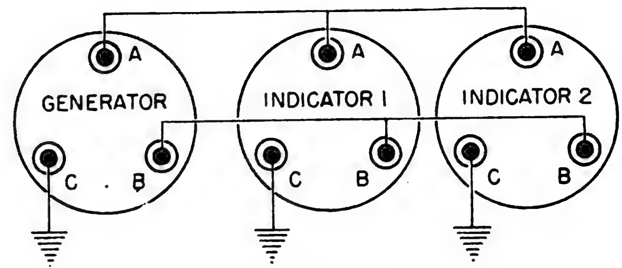


② *Two indicators.*

Figure 56. Synchronous-rotor tachometer wiring diagram ungrounded three-wire system.

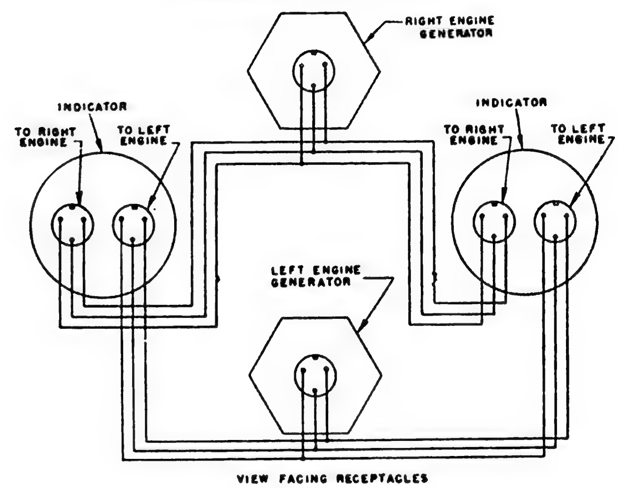


① *One indicator.*

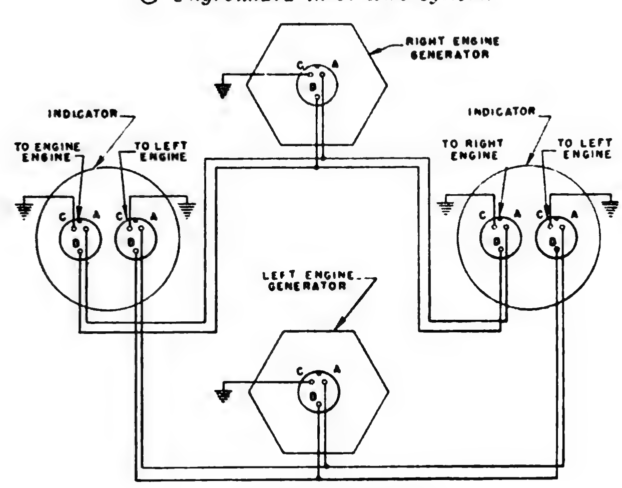


② *Two indicators.*

Figure 57. Synchronous-rotor tachometer wiring diagram —grounded two-wire system.



① *Ungrounded three-wire system.*



② *Grounded two-wire system.*

Figure 58. Wiring diagrams—dual synchronous-rotor tachometer.

cator rotation may be reversed in the same ways as just described for the corresponding ungrounded and grounded single-element tachometers.

c. Installation. The synchronous-rotor tachometer generator is installed on the tachometer drive of the engine. The generator may be of the screw mount (Type I) or the pad mount (Type II) type, both of which are shown in figure 53. The correct size wire, soldered to AN standard plugs, is used for connecting the generator to the indicator.

d. Inspection and Maintenance. All units in this system are sealed except for the wiring hook-up, and any repairs or adjustments necessary to the internal mechanisms are major repairs. No lubrication of the units is required between overhaul periods. In the event of unsatisfactory operation, examine all soldered connections for security and cleanliness, and check the wiring for electrical continuity. If the cause of the trouble is not revealed by this check, replace the equipment.

17. Maintenance

a. All tachometers and synchronism indicators should be checked at regular intervals for the following:

(1) *Proper tachometer indication.* The engines are operated at ground throttle, cruising speed, and full throttle. The "G" file for the airplane should give the proper readings on the tachometer indicators for these throttle settings. If the engine speed indicated is lower than actual speed, the leads may have been connected to the wrong terminals on the indicator. Figures 55 through 58 illustrate the proper connections for counterclockwise rotation of the generator shaft (looking toward the drive shaft end). If clockwise rotation is desired, reverse any two leads in the case of 3-wire connection and *A* and *B* leads in the case of grounded two-wire connection as previously explained in paragraph 16*b*(5).

(2) *Excessive pointer oscillation.* If the pointers oscillate on the tachometer indicators or the synchronism indicator, it will be necessary to check all leads for proper security and anchorage, and the indicators and generators for security of mounting.

(3) *Backward movement of pointer.* If the d-c or a-c indicators read backwards when the engines are operating, the polarities of the generators have been reversed. When this occurs, it will be necessary to change the leads at the terminals on the generators.

(4) *Zero tolerance of pointer.* Zero adjustment of the pointer on the d-c or a-c generator-voltmeter tachometer indicators is accomplished by means of a small screw on the face of the indicator.

b. D-c generator-voltmeter tachometers and synchronism indicators should also be checked for the following:

(1) *Matched generator output.* When used in conjunction with the synchronism indicator, the two d-c tachometer generators are connected to one of the engines of the airplane, one generator to each of the tachometer outlets. The engine is then run at approximately 1,800 rpm, and the synchronism indicator should indicate zero. At operation above this speed, the error should not exceed that given in Technical Orders. If the two tachometer generator outputs are different, they will be removed for bench-test. If proper adjustment cannot be made, the generator and synchronism indicator set is forwarded to the depot and exchanged for a replacement set. This set has already been adjusted so that the indicator will show zero when the tachometers are synchronized.

(2) *Operation of synchronism indicator.* The control-gauge switch is set for the "Synchronizer On" position, and one engine is operated at a higher speed than the other. The synchronism indicator should then indicate a difference between the speeds of the two engines. If the throttles are adjusted until both engines are running at the same speed, the indicator pointer should remain at zero.

SECTION V
FUEL-LEVEL GAUGES

18. General

a. In the operation of an airplane, it is essential for the pilot to know the exact quantity of fuel in the fuel tank or tanks. Thus a fuel-level gauge is necessary, and this must be kept in accurate operating condition at all times. It enables the pilot to judge the permissible duration of flight before it is necessary to refill the tanks or move the selector switch to the auxiliary or reserve tanks. By means of this gauge the pilot can also determine the fuel consumption of an engine over a given period of time. There are many different types of these instruments. The type selected for use generally depends on the size of the airplane on which the instrument is to be installed, and the number and location of the fuel tanks.

b. The instrument is usually composed of a float arrangement in the fuel tank, an indicator in the cockpit, and a means of transmitting an indication of the fuel level from the tank to the indicator. In general, the various kinds of fuel-level gauges may be classified as follows:

(1) Sight glass.
(2) Mechanical.
(3) Hydraulic.
(4) Electrical.

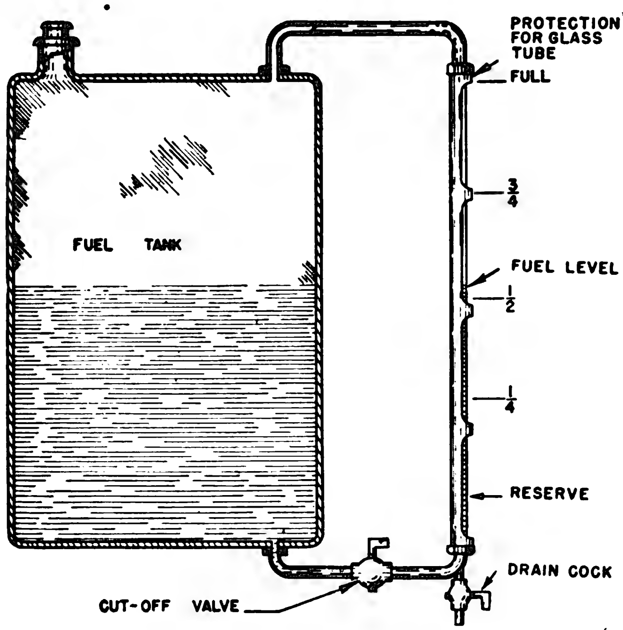


Figure 59. Sight-glass fuel-level gauge.

19. Sight-Glass Gauges

The sight-glass gauge (seldom used) is shown in figure 59. It is the simplest form of all fuel-level gauges. The indicator is usually either a glass or a clear plastic tube running from the top to the bottom of the tank. The tube itself may be calibrated in numbers of gallons, or it may have a metal scale mounted adjacent to it. A shut-off valve may be located at the bottom of the tube. Closing this valve will prevent the loss of fuel if the tube is broken or is to be drained for cleaning.

20. Mechanical Gauges

a. Fuel-quantity gauges of the mechanical type utilize an indicator either above or below the fuel tank. The indicator is connected with a cork or metal float resting on the surface of the fuel. Various designs are described in the following paragraphs.

b. The *float-and-lever fuel-level gauge,* shown in figure 60, depends on direct mechanical linkage for its operation. The float movement is transferred through lever arms and links, or a system of lever arms and gears, to the pointer.

c. The *inverted float gauge,* shown in figure 61, also depends on direct mechanical linkage for its operation. This type of gauge is used in aircraft equipped with a fuel tank located in the upper wing. A rod suspended from the float ends in a disk that is visible through a transparent tube projecting below the wing. The tube is graduated to show the quantity of fuel in the tank. The great objection to this type of gauge is the possibility of breaking of the tube. If this occurs the entire contents of the tank will be lost.

d. The magnetic gauge, employing the principle of magnetic drag, has a magnetized pointer and a permanent magnet. These are separated by a solid diaphragm which acts as a seal and thus prevents leakage of fumes or liquid. In one type (fig. 62), the float lever operates a magnet shaft by means of a gear and pinion. Movement of the magnet shaft changes the position of the permanent magnet, which in turn actuates the magnetized pointer. In another type of magnetic gauge (fig. 63), the magnet shaft is rotated by means of a swivel pin which is attached to the float and operates in a helical slot. Movement of the magnet shaft changes the position of the permanent magnet, which actuates the magnetized pointer. Both types of gauges are installed by screw-

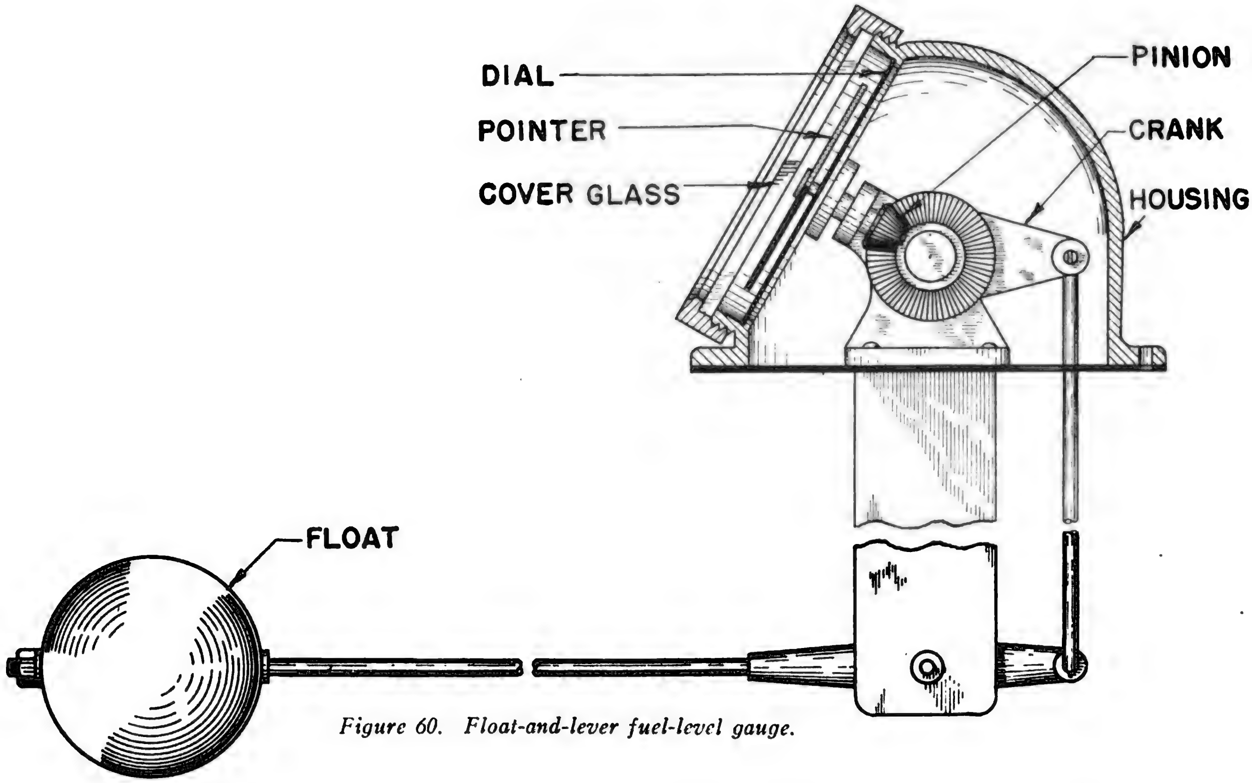


Figure 60. Float-and-lever fuel-level gauge.

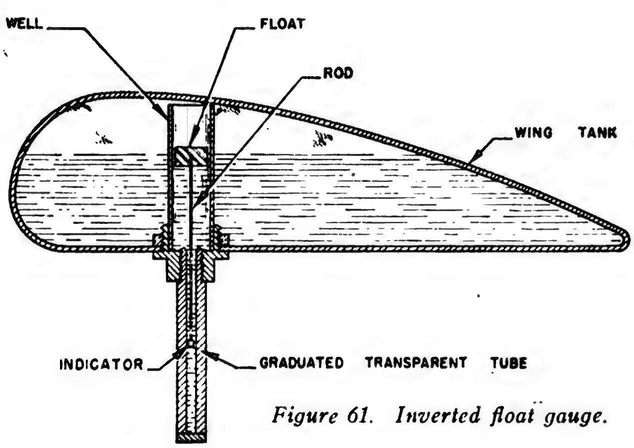


Figure 61. Inverted float gauge.

ing the gauge directly into the tank. The utmost care must be taken to prevent seizing of the threads. The gauge must be tightened or loosened by a series of small fractions of a turn, allowing the heat generated with each turn to be entirely dissipated. Usually about 10 minutes must elapse after each fraction of a turn.

21. Hydraulic Gauges

a. The hydraulic type of fuel-level gauge, shown in figure 64, consists of a closed hydraulic system with a tank unit, an indicator unit, and the flexible tubing connecting these two. The tank unit is made up of two bellows, *A* and *B*, connected by a fixed

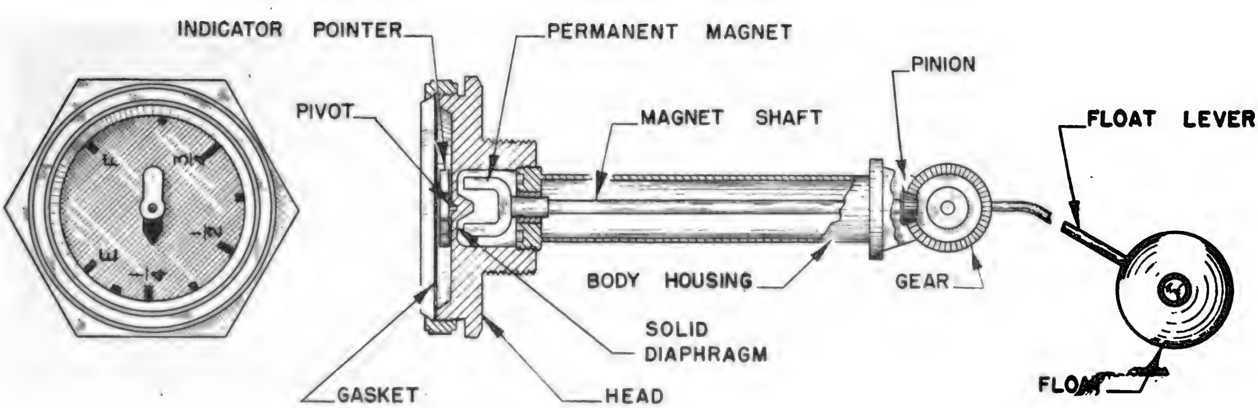


Figure 62. Magnetic fuel-level gauge.

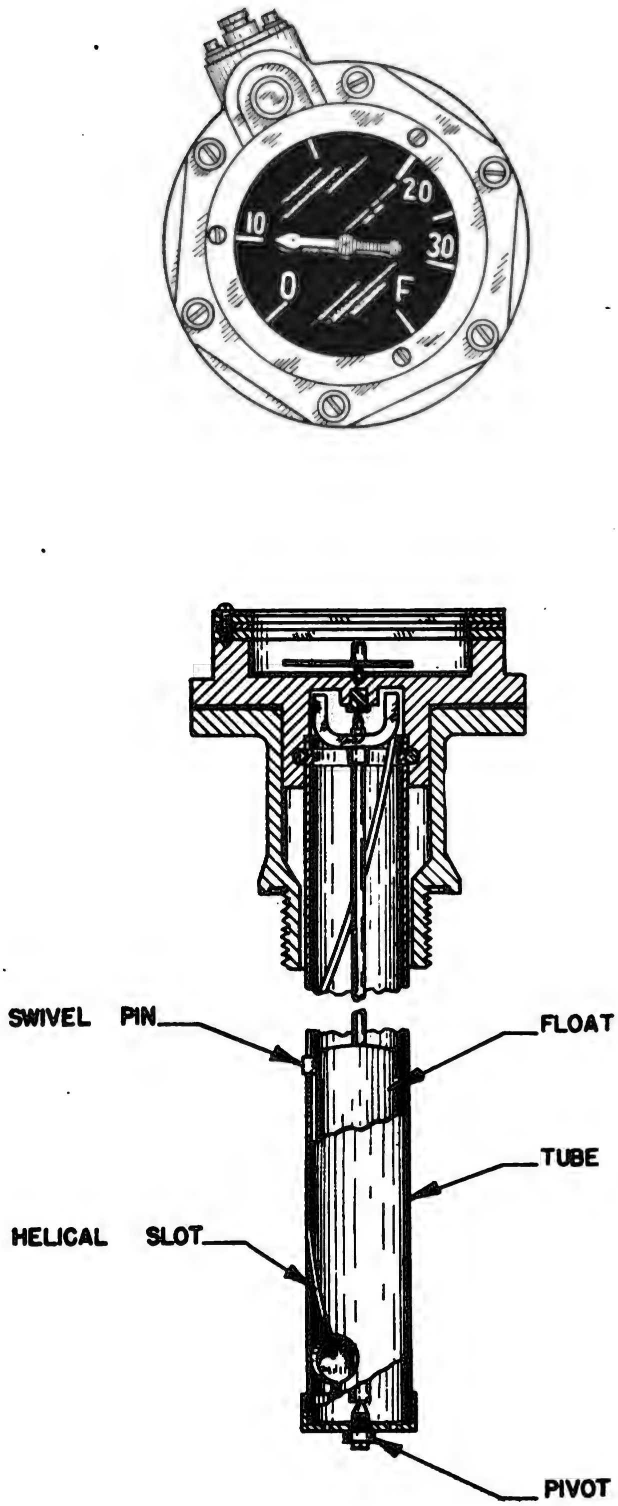


Figure 63. Magnetic fuel-level gauge.

arm to which is attached the tank float. The indicator unit is made up of a similar set of bellows, *C* and *D*, connected by a linkage to which the pointer is attached. As the float in the tank falls, bellows *B* is compressed and bellows *A* expanded. Bellows *D* therefore expands and bellows *C* contracts, so that the pointer is forced to the left. Any increase in pressure, due to temperature expansion of the liquid within the hydraulic system, will not affect the position of the pointer, since the expansion will cause the two bellows in the indicator unit to move inward toward each other and create an equal movement on both sides of the mechanical linkage. The pointer is affected only when both bellows in the indicator unit move in the same direction; this occurs only as a result of the float movement.

b. The objections to this type of gauge are that it may be used only on airplanes having single tanks and that the capillary tubing may become broken or obstructed.

22. Electrical Gauges

a. GENERAL. The principle advantage of electrically operated fuel level gauges is that the quantity of gasoline can be indicated at points which are remote from the tanks. Older installations employ a unit which consists of a dial change indicator and a built-in selector switch. (Fig. 65). The indicator consists of a revolving drum (attached to which is a separate dial for each tank) and a ratiometer or voltmeter type indicating mechanism. (The voltmeter type, which requires a voltage regulator and a separate resistance box, is rapidly becoming obsolete.) When the selector switch knob is turned to a certain tank position, a dial calibrated for that tank automatically comes into view. Each indicator may have a single pointer arranged to move over a 90-, 120-, or 300-° scale, or it may have a number of calibrated scales (with a pointer for each scale) mounted in a single housing. (See fig. 66.) Newer installations employ multiple indicators, which show continuously, the quantity of fuel in each tank. Ratiometer type indicating mechanisms are used in these installations.

b. RATIOMETER MECHANISMS. Two types of ratiometer mechanisms are used. In one type two coils are arranged to move in a non-linear gap of a permanent magnet. The coils carry the pointer, the movement of which is determined by the ratio of the currents in the two coils. In the other type mechanism, a magnetic rotor moves in a field produced by stationary coils. The rotor carries the pointer. The ratio of the currents in the coils controls the magnetic field which, in turn, controls the rotor and the pointer attached to it. (The ratio of the currents in the coils of both types of mechanisms is controlled by a variable resistance in the tank unit.)

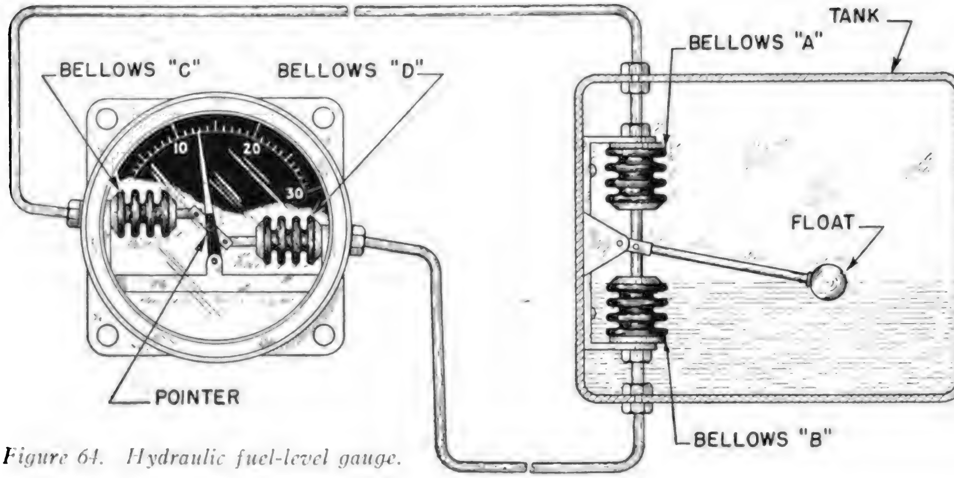


Figure 64. Hydraulic fuel-level gauge.

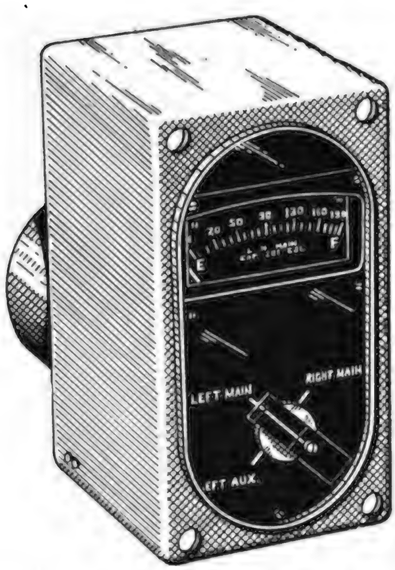


Figure 65. Selector switch-electric fuel-level gauge.

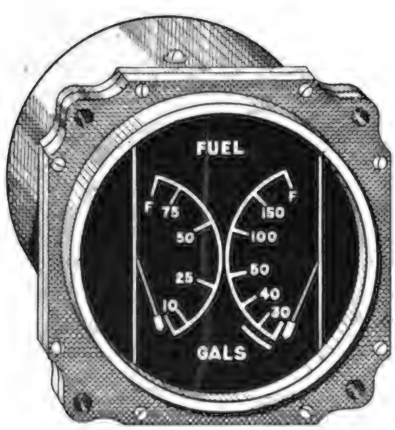


Figure 66. Dual fuel-level indicator.

c. Tank Units. Two types of tank units in general use are the pivoted-arm type and the direct-lift type. In both of these types, a direct mechanical linkage is employed to transmit movement of a float to the movable contact arm of a variable resistance. A metal bellows, which is part of the linkage, serves as a seal and prevents leakage. A low-level, warning switch may be incorporated in either type unit. A third type of tank unit is described in paragraph 22*c*(3).

(1) The pivoted-arm type consists of a housing and fulcrum assembly (which contains the variable resistance, the bellows seal, an electrical connector and, if used, a warning switch), a float arm and linkage assembly, and a float. (See fig. 67.) Movement of the float is transferred through the linkage system to the contact arm of the variable resistance as shown in figure 68. The position of this contact arm determines the ratio of the currents in the coils in the indicating mechanism. (See fig. 69.)

(2) The direct lift tank unit, shown in figure 70, consists essentially of a housing and bearing assembly (which contains the variable resistance, a bellows seal, an electrical connector and, if used, a warning switch), and a tube assembly (which contains a float guide tube and a float). A roller, attached to the float, runs in the spiral guide slot in the tube, therefore the float will turn as it moves up or down. The rotary motion of the float is transmitted to the movable contact arm of the variable resistance by means of a central shaft which is actuated by rollers attached to the float.

(3) A third type of tank unit is the magnetic drag type. This unit consists of a float and gear assembly, a tube and shell assembly, and a Selsyn transmitting element and an electrical connector. Movement of the float is transmitted through a set of gears to a shaft to which is attached a U-shaped magnet. A diamond-shaped magnet, inside the U-shaped magnet, is attached to the shaft of the Selsyn transmitting element. When the U-shaped magnet is turned (by movement of the float), the diamond-

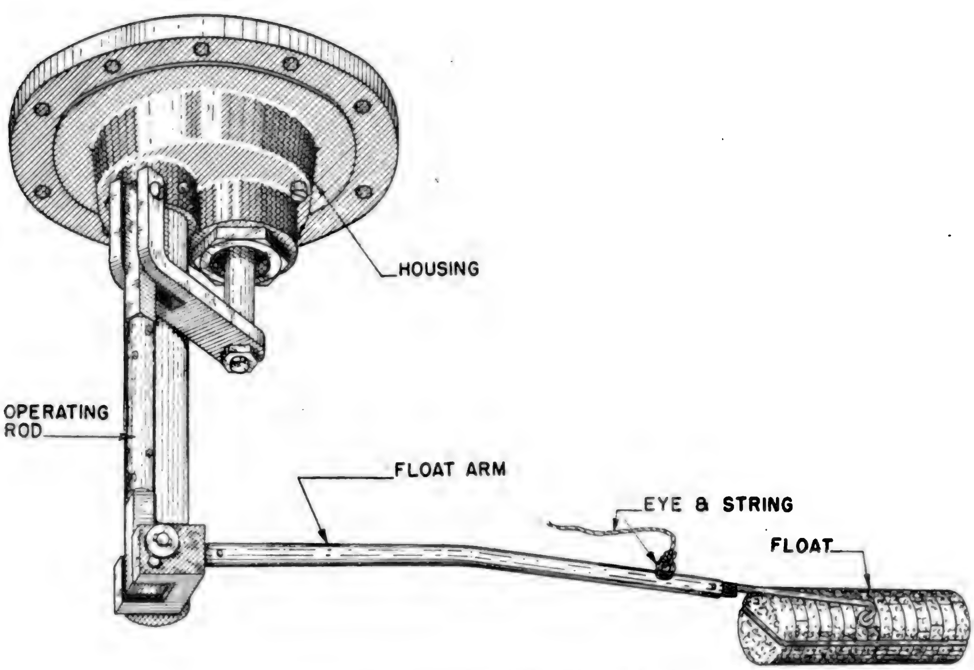


Figure 67. Pivot-arm type of tank unit.

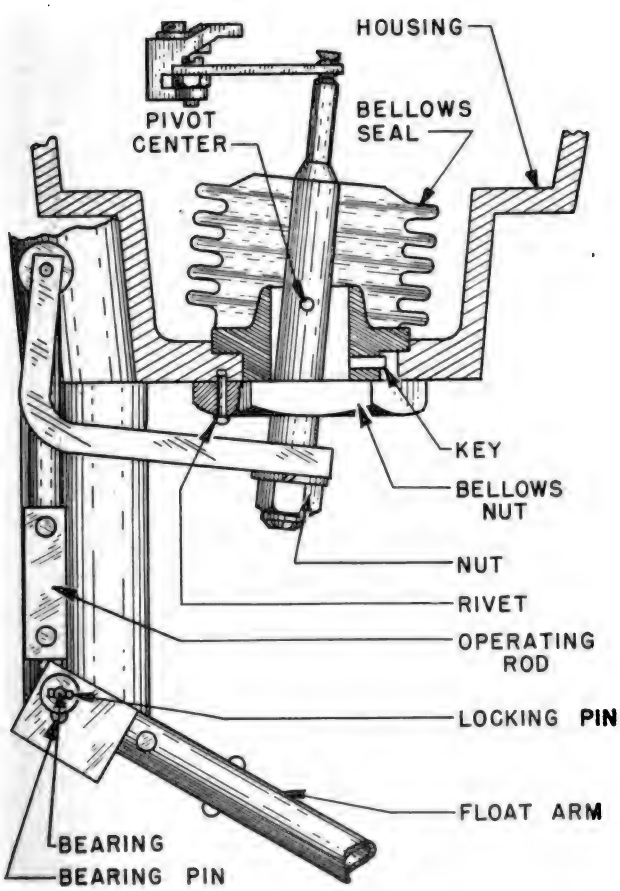


Figure 68. Method of transferring movement of float arm to variable resistance.

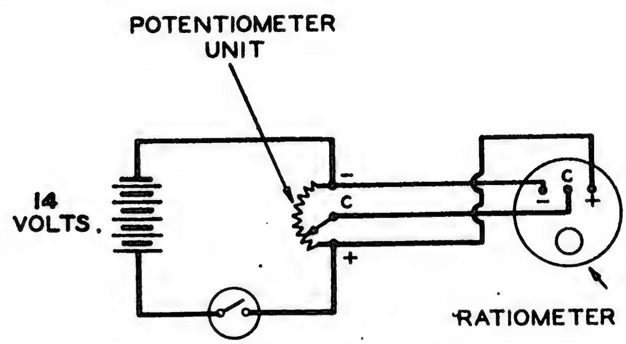


Figure 69. Wiring diagram—ratiometer type fuel-level gauge.

shaped magnet is turned (by magnetic drag) and an indication of this motion is transmitted electrically, to the indicating element. (See sec. VII.)

d. Wiring Diagrams. (1) A schematic wiring diagram of a system incorporating a 90° pointer travel type indicator and one tank unit is shown in figure 71①. By use of a single pole switch, this type indicator can be used with two or more tanks as shown in figure 71②.

(2) A schematic wiring diagram of a system incorporating a 300° pointer travel type indicator and one tank unit is shown in figure 72. A low level warning light is incorporated in this system.

(3) A system containing a dual-pointer indicator and two tank units is shown in figure 73. This system also incorporates a low level warning switch.

(4) The range of operation required in some wing tanks is greater than that of one tank unit. In

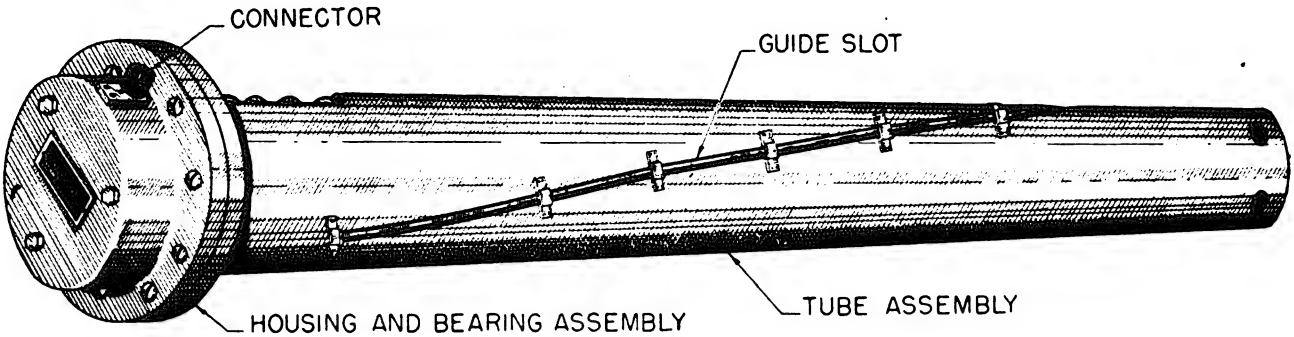
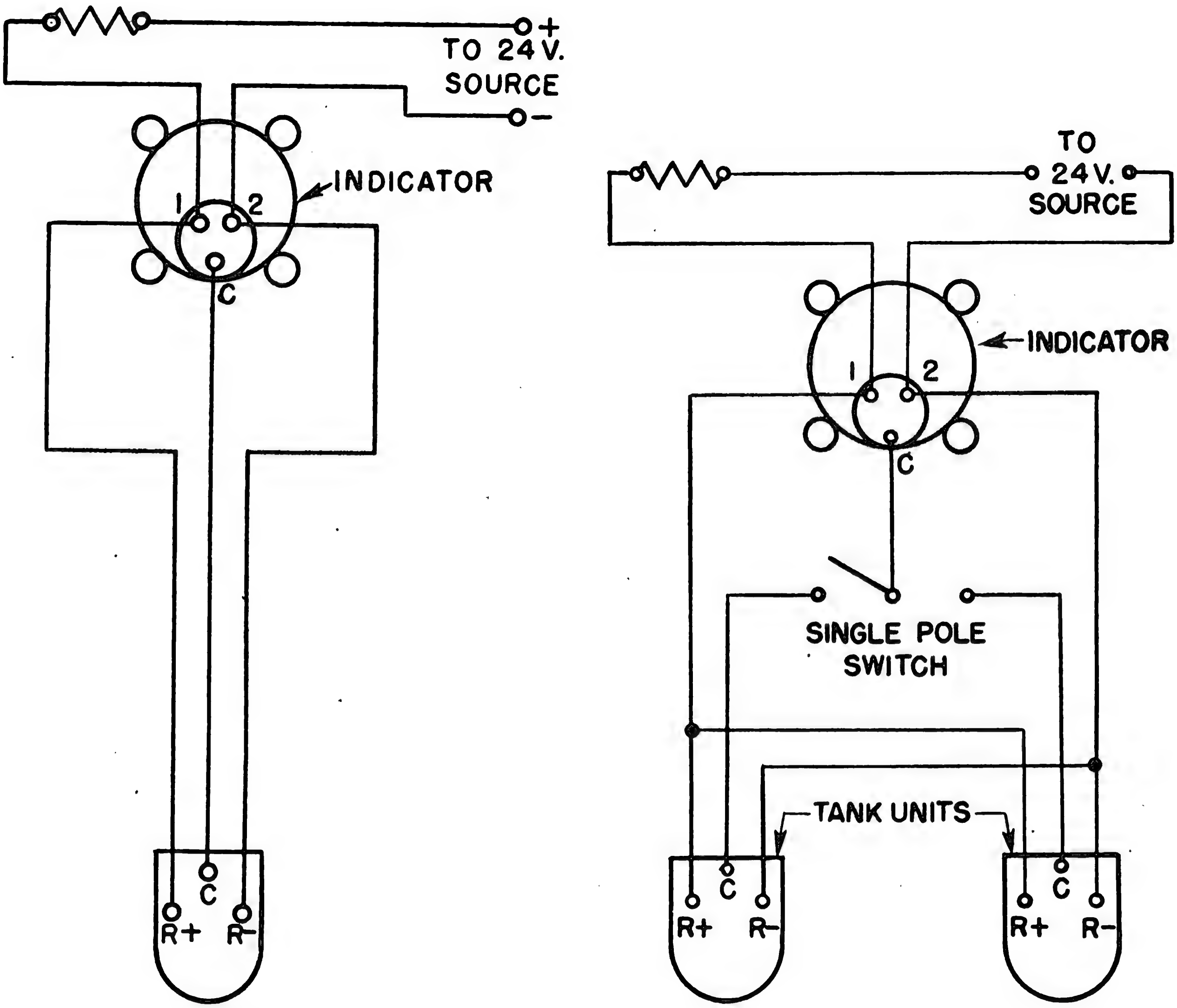


Figure 70. Direct lift type tank unit.



① *One-tank unit.* ② *Two-tank unit.*

Figure 71. Wiring diagram—90° pointer-travel type of indicator.

cases of this kind, two tank units are used-one near the bottom of the tank and one near the top of the tank. A schematic wiring diagram of one system of this kind, called a "two-step" system, is shown in figure 74①. The lower tank unit is equipped with a transfer switch. When the float on the lower tank unit reaches the limit of its upward travel, this switch "cuts in" the upper tank unit which registers

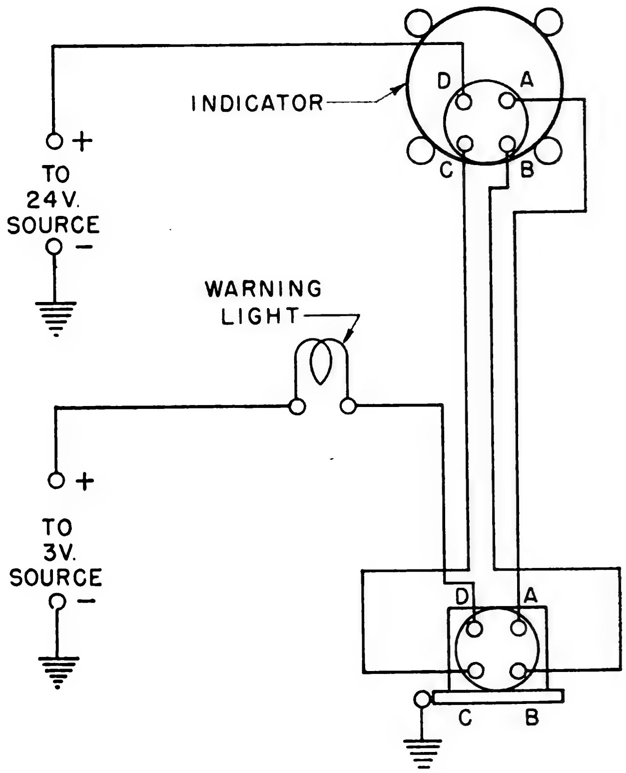


Figure 72. Wiring diagram—300° pointer-travel type of indicator.

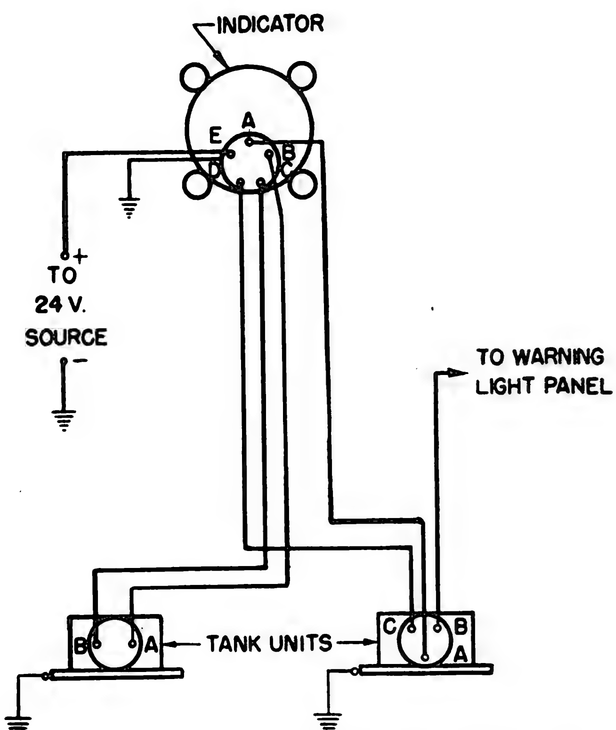


Figure 73. Wiring diagram—points dual type indicator.

fuel level from this point to the "Full" position. In this way, one tank unit complements the other and operation through a wide range is secured.

(5) The two-step system will give erroneous indications when the airplane rotates about the longitudinal axis. The totalizer system, shown in figure 74②, was developed to eliminate this trouble. Each tank unit has two potentiometers connected to a common axis. As the resistance of one potentiometer increases, the resistance of the other decreases.

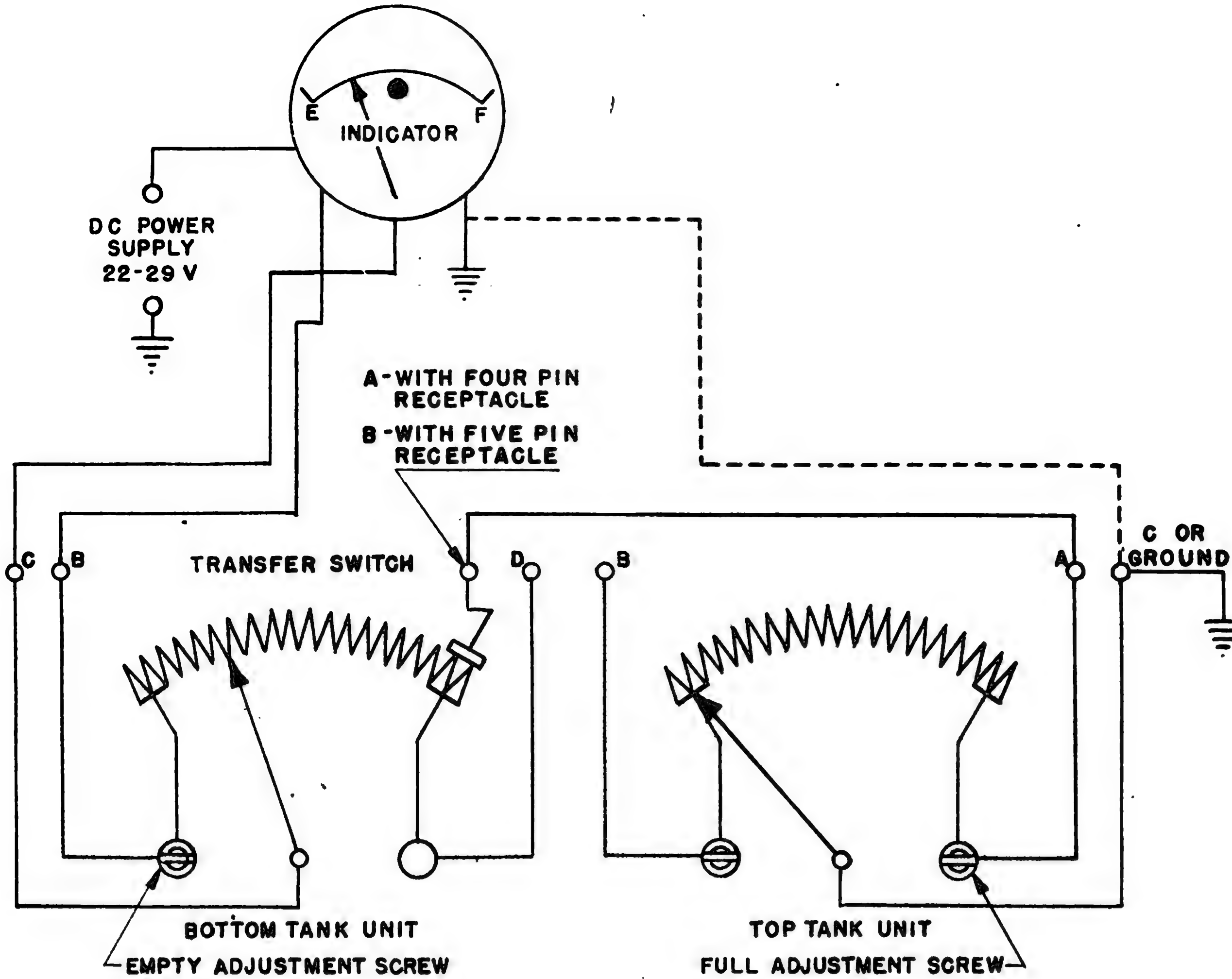
23. Inspection and Maintenance

a. Sight-glass Gauges. Sight-glass types of fuel-level gauges seldom require attention, other than periodic draining, to remove any sediment which may accumulate at the lower end. A drain plug is incorporated in the bottom of the tube for this purpose. In case of tube breakage the unit is replaced with a new one. During periodic inspections, the entire length of the tube should be checked for cracks. The connections in which the tube is seated should be inspected for looseness, decomposed rubber fittings, loose clamps, or any other defect that might result in a leak. It is apparent that the sight-glass type of fuel-lever gauge is accurate only when the airplane is in a level flying position. For this reason level indicators are provided.

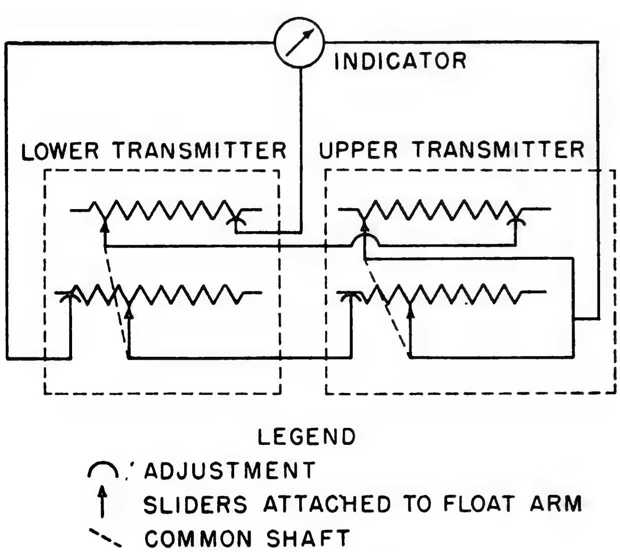
b. Mechanical Gauges. (1) Mechanical-type gauges often fail to function properly. The principal reasons for failure are sticking or binding of the float in the float well; loss of buoyancy of the float, which may be caused by fuel soaking into the float (in the case of wood floats) or by leaks (in the case of metal floats); sticking, binding, or breaking of the mechanism connecting the float to the gauge.

(2) Any of these troubles would necessitate removal of the gauge from the tank in order to remedy the malfunction. Extreme care should be exercised in removal so as not to damage the gaskets and threads at the tank openings. Proper movement of the float and operation of the pointer can then be checked either by hand or by using any open vessel of liquid. An unserviceable indicator is replaced with one which has a suitable scale range for the particular tank on which it is to be used. Thread-lubricating compound will be applied to the threads before the new gauge is installed.

c. Hydraulic Gauges. Hydraulic fuel-level gauges which have broken or leaky capillary tubes should be removed and immediately forwarded to the depot, from which they will be shipped to the manufacturer for repair. If excessive error is apparent at the empty or full position, it is due to improper pointer travel, which may be corrected by means of the stroke adjustment in the tank unit. If the position of the pointer is inaccurate throughout



① *Two-step tank-unit system.*



② *Totalizer type system.*

Figure 74. Fuel-level indicator systems.

the scale range, it may be corrected by means of the position adjustment within the tank unit. Failure of the pointer to show any reading is usually due to either a break in the lines or a defective float. Either difficulty will necessitate replacement of the defective assembly.

d. Electrical Gauges. Maintenance consists of replacement of broken leads, repair of loose connections, readjustment of stroke and replacement of major parts of the installation. If excessive error is apparent at the "Empty" or "Full" position, it is due to improper pointer travel in relation to float travel, and the stroke must be readjusted. This is done by means of screws in the potentiometer assembly in the tank unit. (See fig. 75.) With the float at the bottom of the tank, turn screw *A* until the pointer is exactly on the "Empty" mark. Raise

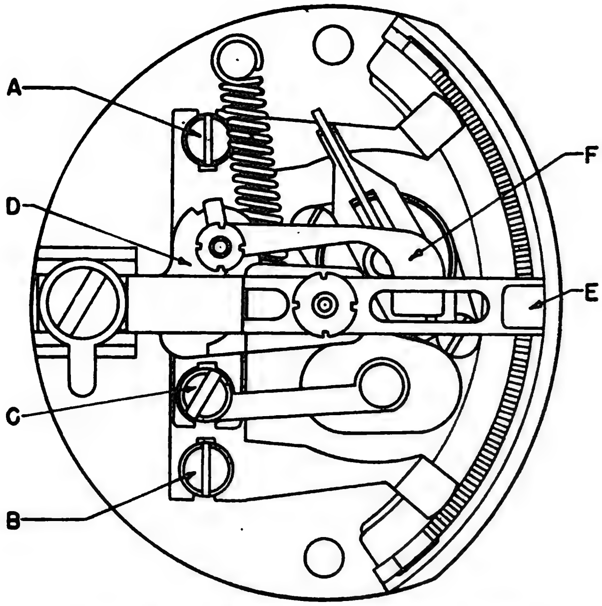


Figure 75. Tank-unit potentiometer assembly.

the float until it touches the top of the tank. (If the direct lift tank unit is being adjusted, it must be removed from the tank so the float can be moved. If the pivoted arm type unit is being adjusted, use the stroke setting string as shown in figure 76.) If the pointer is not on the "Full" mark, turn screw *B*

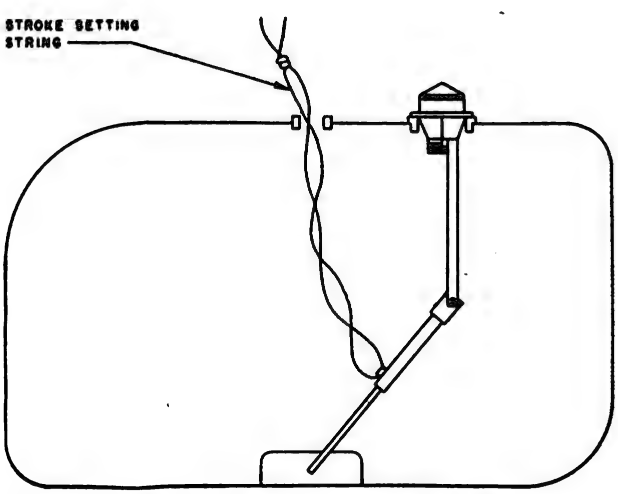


Figure 76. Use of stroke-setting string.

(fig. 75) until the pointer indicates "Full." Check top and bottom positions two or three times and readjust if necessary. The pointer should indicate "Full" when the float is at the top of the tank and "Empty" when it is at the bottom.

(1) For some tank units it may be necessary to "centralize" the pointer, (adjust its travel so that it is the same amount off at the "Full" and "Empty" marks) before adjusting the stroke. This is done by moving the shoe *E*, as shown in figure 75. (This shoe is held to part *D* by a friction fit.)

(2) The warning switch (if used) is adjusted by holding the float at the warning level desired and rotating switch shoe *F* (fig. 74) until the warning lamp lights.

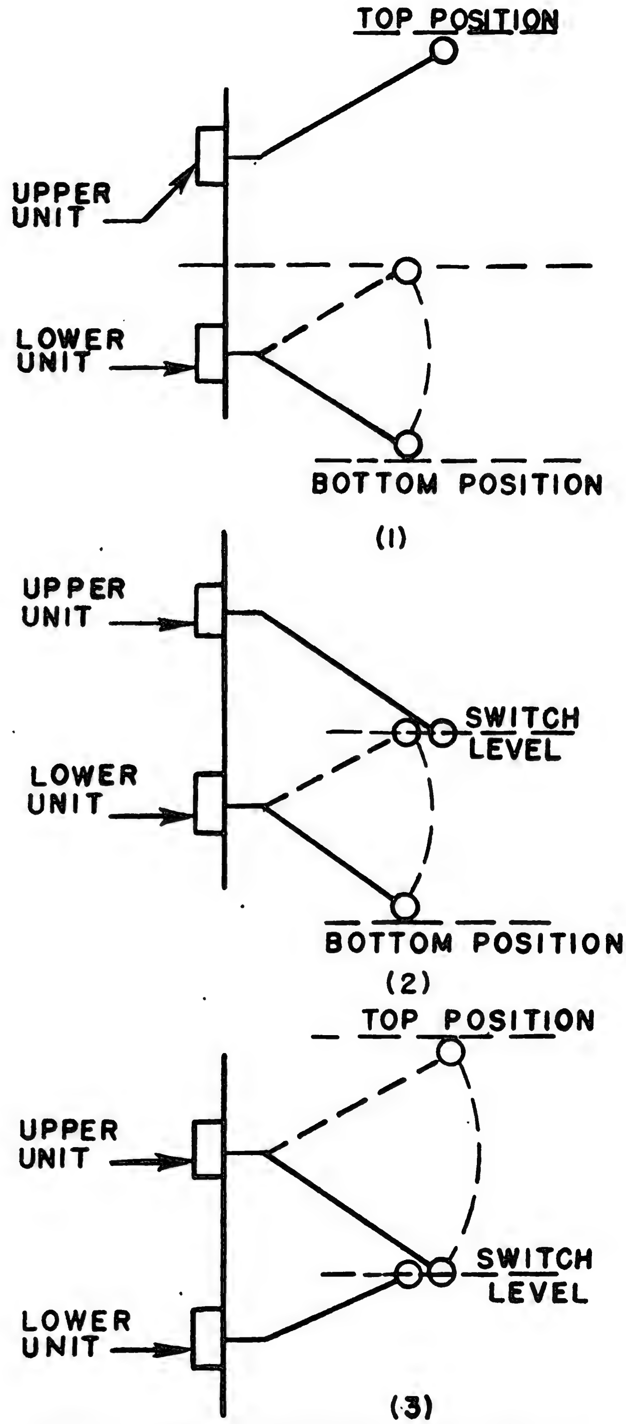


Figure 77. Adjustment of two-step system tank units.

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(3) In the two step system, the bottom tank unit is adjusted first. While holding the upper tank unit float arm in the upper position, raise the lower tank unit float arm from the lower to the upper position, as shown in figure 77 (1). The action of the indicator pointer should be noted. It should travel to the green arc or dot at the middle of the scale, then suddenly jump to "Full" position during the last ¾-inch travel of the float arm. To adjust the upper tank unit, hold its float arm in the lower position and move the lower tank unit float arm to the upper position, as shown in figure 77 (2). The pointer should not jump more than one-pointer width when the bottom tank unit float arm reaches the upper position. While holding the bottom tank unit float arm in the upper position, move the top tank unit float arm toward the upper position, as shown in figure 77 (3). The indicator pointer should start to move from the middle of the scale during the first ¾-inch movement of the float arm. If the above action is not obtained, consult applicable Technical Orders for methods of adjusting tank unit.

SECTION VI
FUEL-MIXTURE INDICATOR

24. General

a. The fuel-mixture indicator is an instrument that indicates the fuel-air ratio of the mixture entering the engine. This is accomplished by measuring the heat-conducting properties of the exhaust gases. The instrument is used as a guide to the pilot for setting the manual mixture control. Formerly, in airplanes with fixed-pitch propellers, the mixture control was set by a method based on the decrease of engine rpm as the mixture was leaned or enriched. When constant-speed propellers are used, another method of indicating the mixture is necessary, since the rpm of the engine is not affected even when the mixture is lean enough to damage the engine or rich enough to cause excessive fuel consumption.

b. Fuel-mixture indicators are of two general types: those for single-engine airplanes and those for multiengine airplanes. Although the construction features of the two are different, their principle of operation is exactly the same.

25. Principle of Operation

a. Operation of this instrument depends on the difference in thermal conductivity (heat-conducting property) of two gases and their varying proportions in the exhaust.

b. The engine exhaust is composed of various gases (fig. 78), but for fuel-air ratio analysis, only

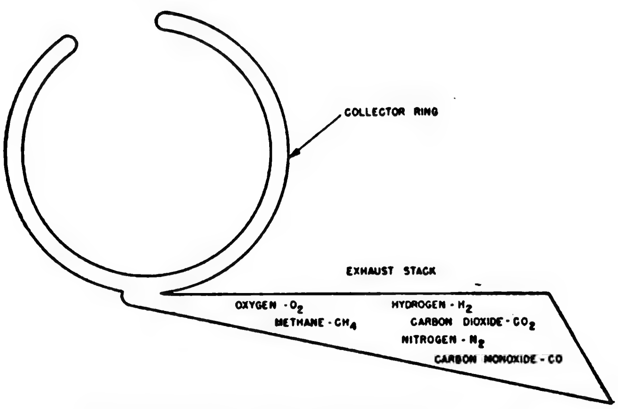


Figure 78. Constituents of exhaust gases.

carbon dioxide (CO_2) and hydrogen (H_2) need be considered. The proportion of these gases in the exhaust varies, depending upon the fuel-air ratio of the fuel mixture supplied to the combustion chambers of the carburetor. The proportions of the other gases in the exhaust vary also, but their thermal conductivities are approximately equal to that of air and do not affect the operation of the instrument.

c. A sample of the exhaust gases is brought through the analysis cell (fig. 79), where it is analyzed. The analysis cell contains four platinum spiral resistors. Two of these, *A* and *C*, are connected through a filter to the exhaust gases. The other two, *B* and *D*, are sealed in a chamber and exposed to moisture-saturated air (provided by a removable wick.) The four resistors are heated a definite amount by an electric current, and are all at the same temperature when no exhaust gases are present. However, when exhaust gases pass around resistors *A* and *C*, part of the heat of these resistors is carried away. The higher the proportion of H_2 in the mixture, the greater the cooling of these resistors and the lower their resistance to electric current. This resistance is "compared" with that of resistors *B* and *D*, and the difference causes a deflection of the indicator pointer.

26. Description

a. SINGLE-ENGINE AIRPLANES. The fuel-mixture indicator for a single-engine airplane consists of two sampling tubes, an analysis cell, No. 18 gauge wire, and an indicator unit.

(1) Sampling tubes (fig. 80) conduct the exhaust gases to and from the analysis cell. The inlet tube is covered over part of its length with asbestos loom to prevent rapid cooling of the exhaust gases and resultant condensation of moisture.

(2) The analysis cell contains a filter for removing carbon particles from the exhaust. Replaceable, stainless-steel wool is contained in the filter chamber which is connected by a small opening to an inner chamber. In this chamber are the small platinum resistance wires, or resistors.

(3) The analysis cell is connected to the indicator unit, as shown in figure 81.

(4) The indicator unit (fig. 82) includes a mechanism for indicating the fuel-air ratio and a ballast tube for maintaining a constant voltage. The ballast tube is a resistor sealed in a hydrogen-filled glass bulb. The 12- or 24-volt airplane battery circuit is used to energize the electrical system of the instrument. By means of the ballast tube, variations in current to the indicator, are reduced to negligible proportions. In later types, the ballast tube is mounted on the analysis cell.

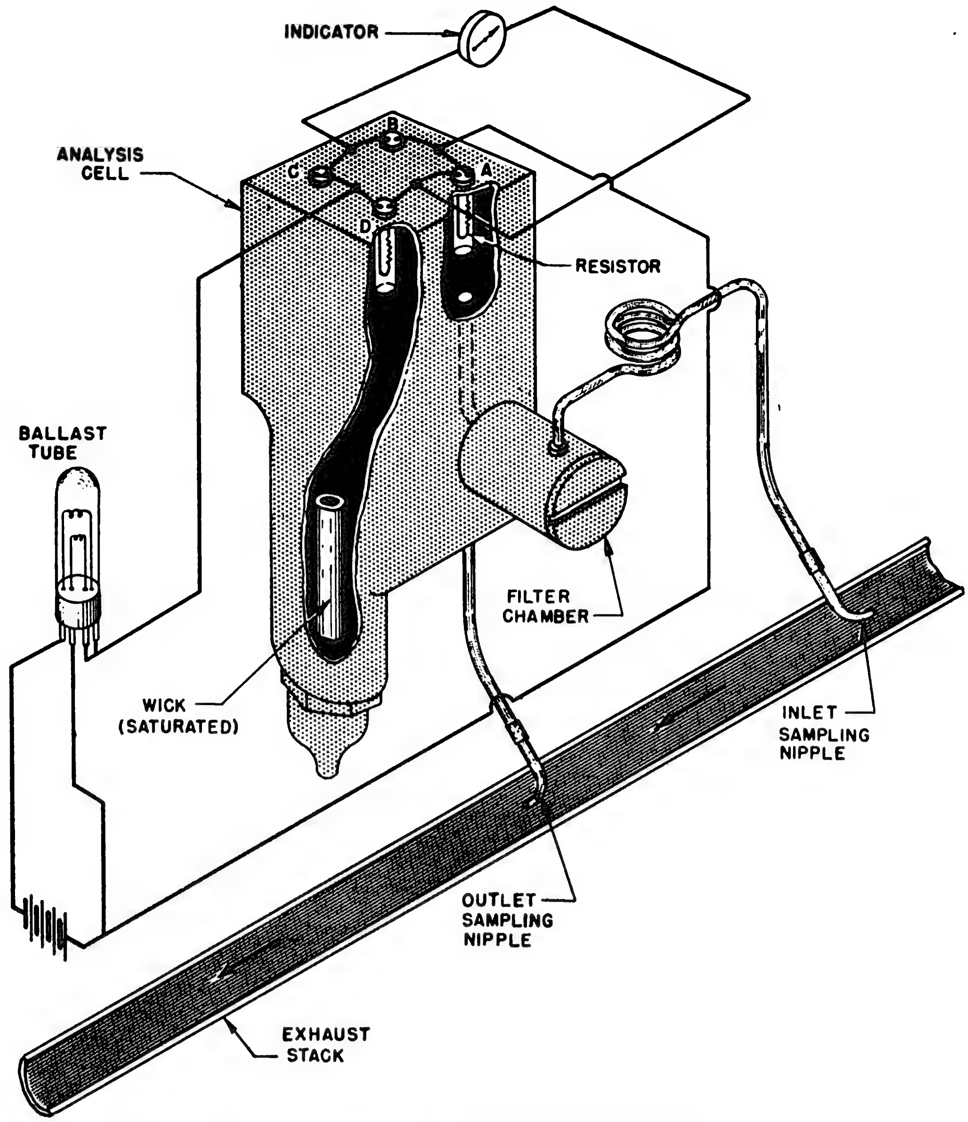


Figure 79. Analysis cell—fuel-mixture indicator.

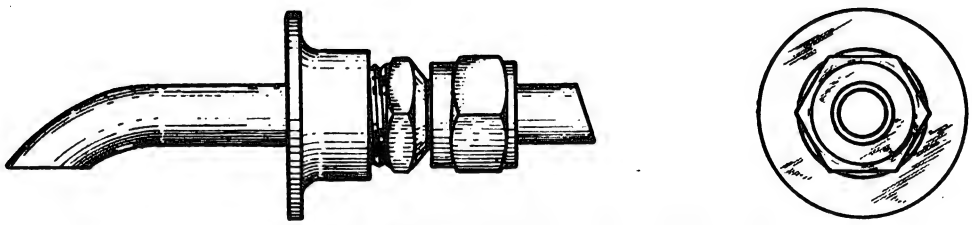


Figure 80. Sampling tubes for fuel-mixture analysis cell.

b. Multiple-engine Airplanes. (1) The fuel-mixture indicator for dual-engine airplanes consists of four sampling tubes, two analysis cells (one for each engine), a junction box, and an indicator unit, as shown in figure 83. The sampling tubes and analysis cells are similar to those for the single-engine airplane. The junction box includes the ballast tube, two resistors, a rheostat, and a panel for connections to the analysis cells and indicator. The indicator contains two mechanisms for indicating the fuel-air ratio, to each of which is attached a pointer.

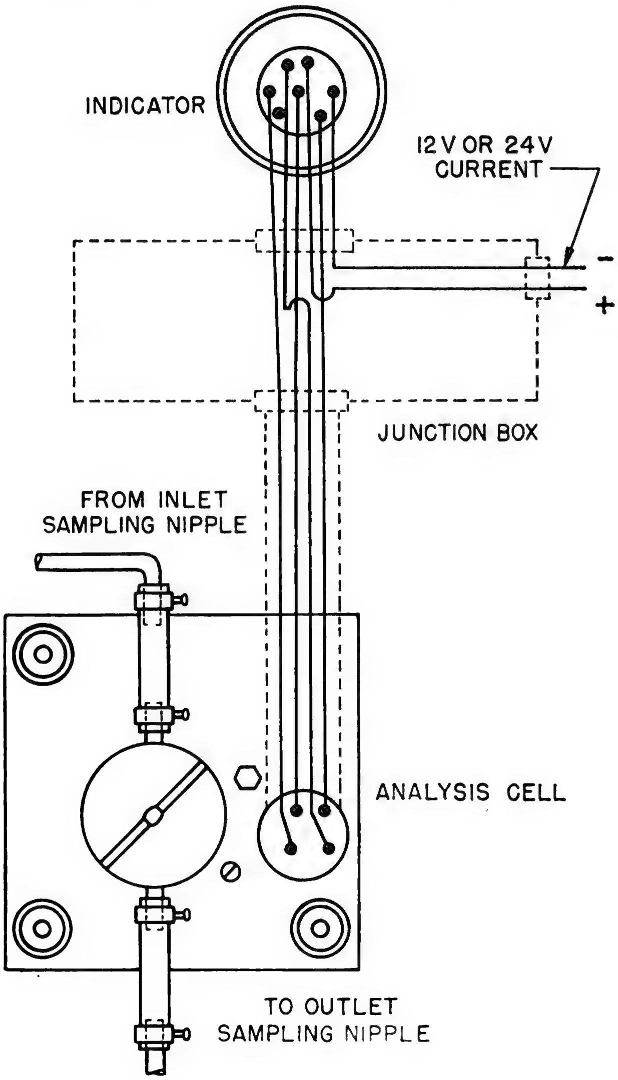
(2) In four-engine airplanes each engine requires one analysis cell and the two sampling tubes. Only one junction box and one indicator unit, however, are required for the whole installation. The

use of a selector switch makes it possible to connect the junction box and indicator unit with the analysis cells of either pair of engines.

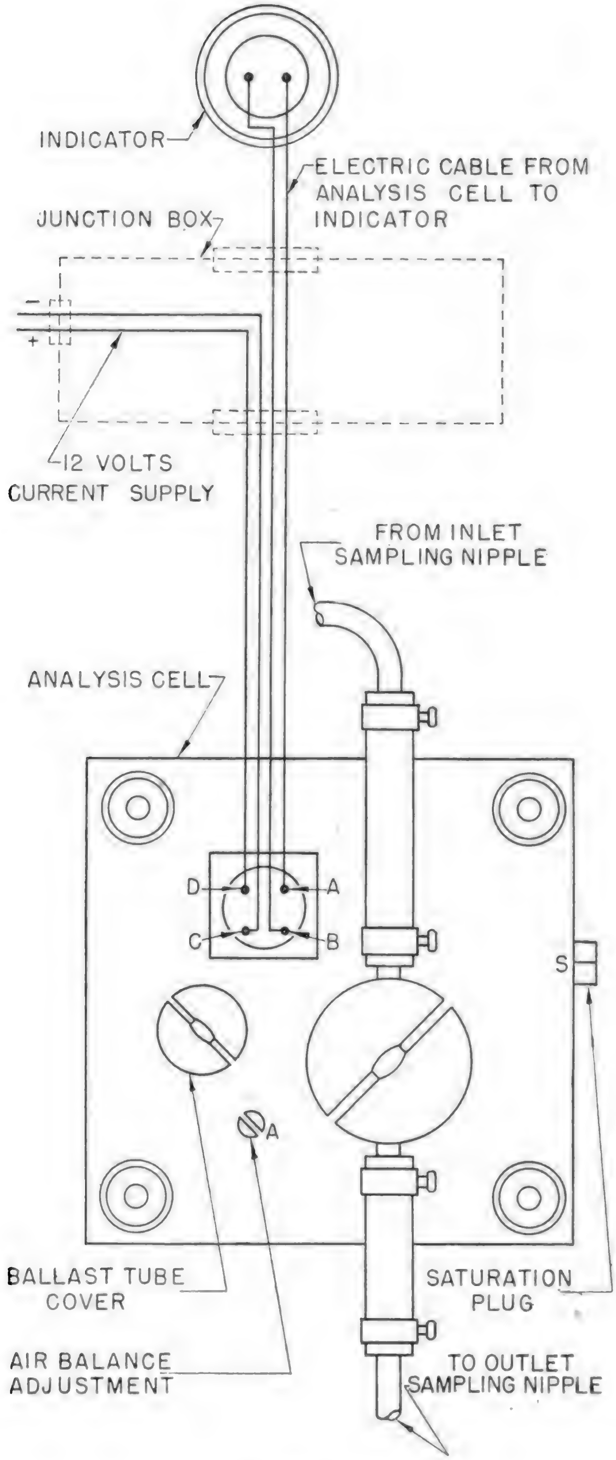
27. Operation

a. Assume that the two resistors *A* and *C*, (fig. 77) are exposed to exhaust gases from an engine operating on a lean mixture. Because such a mixture produces an abundance of CO_2 in the exhaust, and because CO_2 is not as good a conductor of heat as air, less heat is carried away from the resistors *A* and *C* than from *B* and *D*, which are exposed to moisture. Since the temperature of resistors *A* and *C* is higher than that of *B* and *D*, their resistance is higher. This difference in resistance, through the action of a galvanometer in the unit, causes the indicator pointer to swing to the "lean" side.

b. Suppose that the carburetor mixture is enriched. Because such a mixture produces an exhaust richer in H_2, and because H_2 is a better conductor of heat than either CO_2 or air, more heat is carried away from the two resistors *A* and *C* than from



① *Old type.*



② *New type.*

Figure 81. Wiring diagrams—fuel-mixture indicator.

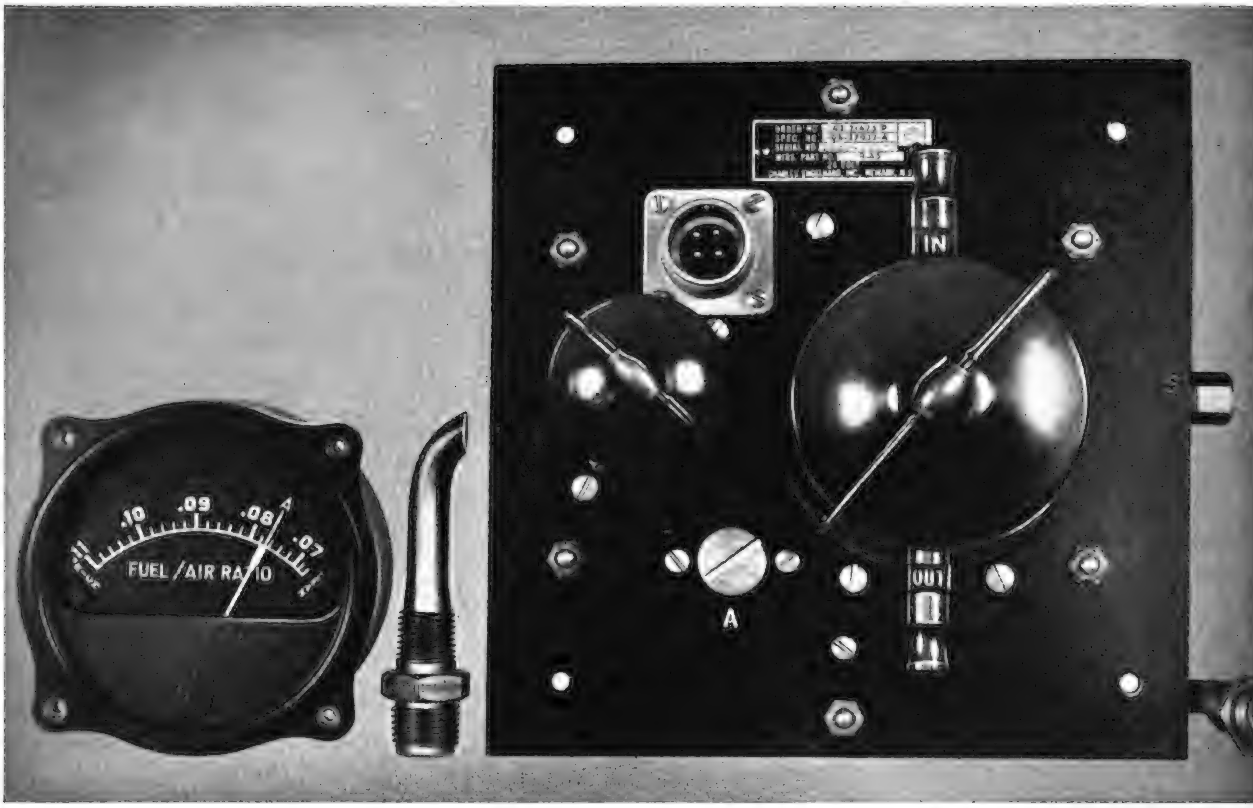


Figure 82. Fuel-mixture indicator.

B and *D*. The temperature of resistors *A* and *C* is lowered and their resistance decreases. This action unbalances four resistors in the opposite direction, and causes the indicator pointer to swing to the "rich" side.

c. There is one important exception to normal operation of the instrument. If the mixture is leaned to a point where detonation (explosive combustion of the mixture within the cylinder) occurs, large amounts of H_2 will be liberated, causing the indicator to swing to the "rich" side. If this indication is misunderstood and the mixture leaned further, the extent of the detonation will increase and a still richer indication will be obtained. If properly understood, this occurrence will be a warning of detonation, which is quite dangerous and can, if allowed to continue, result in total engine failure. Slight detonation is usually indicated by a fluctuation of the pointer.

28. Installation

a. Fuel-mixture indicators are installed according to specific instructions for the particular airplane. The following instructions are general.

(1) *Sampling tubes*. The sampling nipples, as shown in figure 78, may be installed by screwing them into the threaded flanges which are welded to the exhaust stack or collector ring. The inlet nipple is turned upstream (facing the exhaust gases). It should not be less than 12 inches from the exhaust-stack outlet. When the nipple is in this position, the outside air will not dilute the gas at low engine speeds. This method of installation causes the nipple to receive an average gas sample from the greatest possible number of cylinders. The outlet nipple is turned downstream (away from the exhaust gases), in a position where the greatest suction is available, to permit proper circulation of the gas.

(2) The copper or stainless-steel tubing is connected to the nipples by flange fittings and to the analysis cell by means of short lengths or rubber hose and hose couplings. (See fig. 81.) To prevent transmission of vibrations from the gas line to the cell, the short lengths of rubber hose should be at least 1-inch long between the ends of the tubing and the inlet and outlet pipes of the cell.

(3) Usually the analysis cells are placed so that the gas flows downward from the inlet tubing. If this is not possible the line must conform to the specifications given in Technical Orders.

b. Analysis Cell. The analysis cell may be mounted on suitable brackets adjacent to the engine.

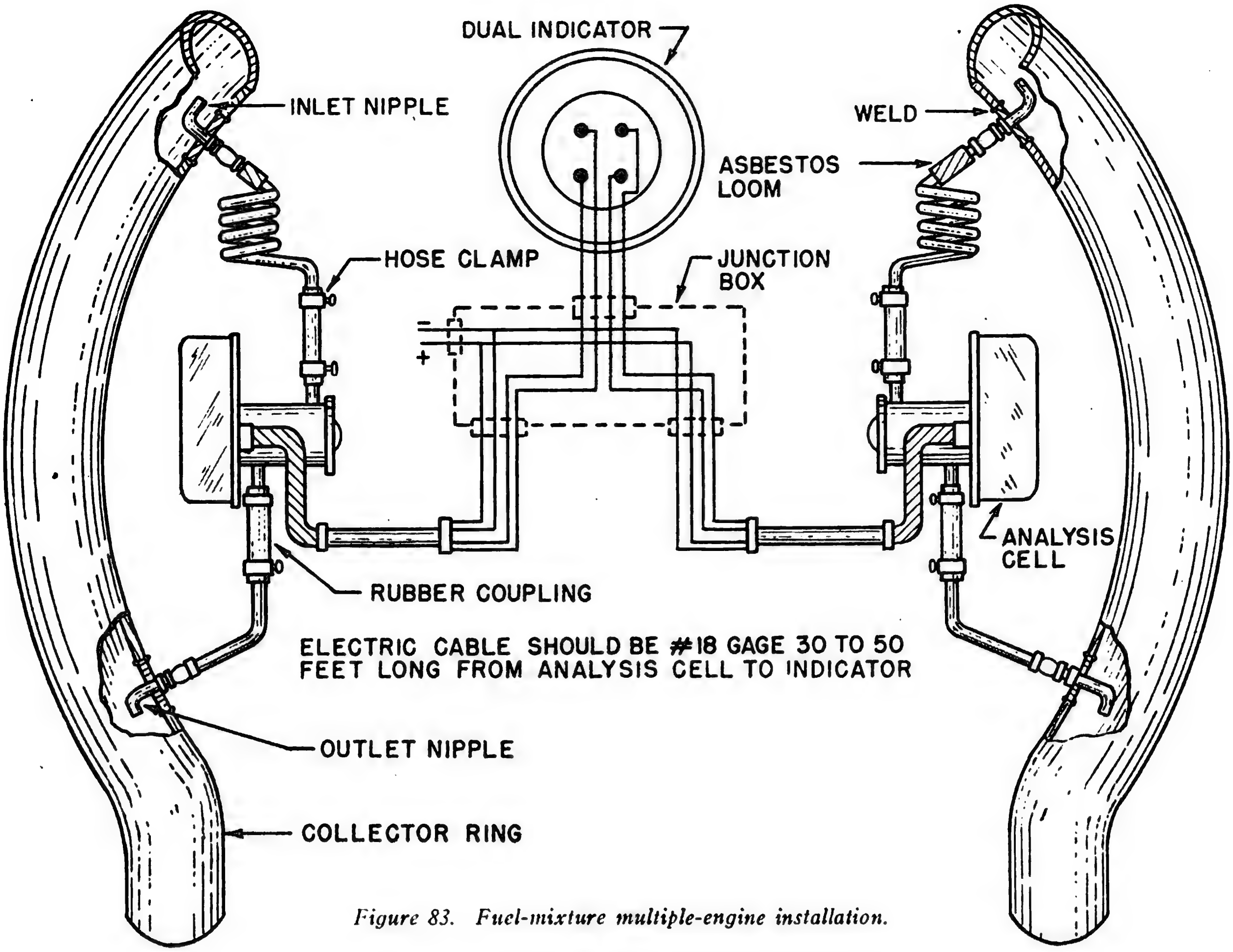


Figure 83. Fuel-mixture multiple-engine installation.

In a single-engine airplane it is usually mounted on the fire wall or some other convenient location (but not within the cabin, where a gas leak might be dangerous). In a multiple-engine airplane an analysis cell is usually mounted at some suitable place in the nacelle. In case of low temperatures, the outlet line and filter may require insulation.

c. Electrical Connections. The electrical connections from the analysis cell to the indicator as well as the connections to the current supply should be made of the correct size and length. The junction box unit for making the connections between the analysis cell and the indicator unit may be installed at any convenient point.

d. Indicator Unit. The indicator is installed on the panel from the rear. It may be easily removed when necessary.

29. Inspection and Maintenance

Fuel-mixture indicators will be checked at regular intervals for the following:

a. Mechanical Zero. To adjust mechanical zero, the current supply should be off and the indicator pointer should rest at the line marked *A* on the scale. If it is either to the right or left of this point, the condition may be corrected by turning the small screw on the face of the instrument. Lightly tap the indicator while this adjustment is being made.

b. Electrical Zero. The position of the pointer on electrical zero should likewise be at the line marked *A* on the scale, that is, the same as mechanical zero. Before checking and adjusting electrical zero, make sure that the humidity in the wick and in the filter chamber is the same. To accomplish this, see that mechanical zero is properly set. Then wet the wick in the vapor plug of the analysis cell. Remove the filter cover and steel wool from the filter chamber of the analysis cell, allowing about 10 minutes for any residual gas to be displaced by fresh air. Then inside this chamber place a clean, wet rag that has been slightly wrung out, and replace the cover. Allow the instrument to stand thus for about 30 minutes. The current is then turned on. The pointer on the indicator should align with the *A*

point on the scale within the time specified in Technical Orders. If it does not, it may be adjusted to this position by turning the knob or screw of the rheostat on the analysis cell. The wet rag should then be removed from the filter chamber and the steel wool and filter cover replaced. When replacing the wool, push it in sufficiently to clear the opening of the inlet pipe.

c. FILTER. To clean the filter, remove the filter material from the analysis cell and wash it thoroughly with gasoline to remove the oil and carbon residue. Then rinse it in clean water and shake the excess water off thoroughly before replacing it. Press in the wool so that the inlet pipe is not covered. In time, this wool may become corroded and decomposed. Deteriorated wool should be replaced with a new steel-wool filter.

d. SAMPLING NIPPLES AND LINES. The sampling nipples and gas lines should be cleaned out and the joints tightened wherever necessary. To clean the sampling lines and nipples, break the connection at the cell, insert a discarded tachometer shaft into each line, first one and then the other and rotate the discarded shaft several times. It may be necessary to repeat this procedure several times in order to dislodge the condensate and carbon residue.

e. GENERAL. In the event of unsatisfactory operation, the following points should be checked before removal of the instrument from the airplane:

(1) See that proper voltage is being supplied to the instrument (12 or 24 volts).

(2) Check the wiring and make sure that no frayed strands of wire touch the adjoining terminals. See that no wires are broken off and that all connections are tightly made.

(3) Check the flow to be certain that a gas sample is reaching the analysis cell. Failure of the instrument to follow changes in fuel-air ratio usually indicates a clogged line. If the flow has been cut-off, inspect the inlet and outlet nipples in the exhaust stack to make certain they are not burned off or plugged with carbon.

(4) Check the sample lines to make sure there are no condensate pockets or ice formations which might cause stoppage.

(5) Check each unit in turn by substituting, if possible, a unit of known performance in its place.

SECTION VII
REMOTE-READING SELF-SYNCHRONOUS INSTRUMENTS

30. General

a. By means of remote-indicating self-synchronous instruments, engine and control functions may be measured or registered at the most convenient location and the measurements or function indications transmitted electrically to indicators on the instrument panel. In large multiple-engine airplanes, such indicating systems make possible the elimination of long, troublesome tubing and capillary lines.

b. Remote-reading self-synchronous instruments are generally divided into two classes: those operating on alternating current and those operating on direct current. The two types differ somewhat in principles of operation and in application. They are used to indicate respectively, the following:

Alternating-current (Autosyn) systems	*Direct-current (Selsyn) systems*
Manifold pressure	Flap and retractable landing-gear positions.
Fuel pressure	Fuel level
Fuel level	Gun-ammunition supply
Fuel flow	
Oil pressure	
Oil temperature	
Carburetor-mixture and air temperature	
Engine rpm	
Positions of retractable landing gear, flaps, bomb doors, control surfaces, etc.	
Radio compass bearing	

① *Transmitter.*

② *Indicator.*

Figure 84. A-c self-synchronous transmitter and indicator.

31. Synchronous Alternating-Current Instruments

a. GENERAL. In the a-c synchronous system, a mechanism of standard type is used to measure functions (pressure, rpm, temperature, etc.) or register positions (as of flaps or landing gear) at the most convenient point. Through a mechanical linkage, this mechanism changes the angular position of the rotor of a transmitter. The transmitter (fig. 84①), by electrical means, causes the rotor of the indicator (fig. 84②), to which it is connected, to move to a corresponding position. At all times a pointer, attached to the indicator rotor, shows on the indicator dial, the value measured or the position noted. To prevent damage from accidental short circuits and overloads, individual fuses are provided in a common fuse box in the power-supply (rotor) circuit of each transmitter indicator system.

b. TRANSMITTERS. (1) Transmitters for different instruments differ only in the mechanism used to measure or register the particular function. A transmitter incorporating a Bourdon tube is shown in figure 85. The oil-pressure transmitter uses a Bourdon-tube mechanism; the fuel-pressure transmitter, a diaphragm; the manifold-pressure transmitter, an aneroid; the thermometer, a vapor-pressure mechanism; the tachometer, a centrifugal device; the fuel-level gauge, a float mechanism; the position indicator and the ammunition-rounds counter, a gear assembly. Mechanisms of these types are described elsewhere in this manual.

(2) The electrical parts of these various transmitters are the same. The transmitting motor consists of a single-phase, two-pole rotor within a three-phase, two-pole *Y*-connected stator. The rotor contacts are of the hairspring type.

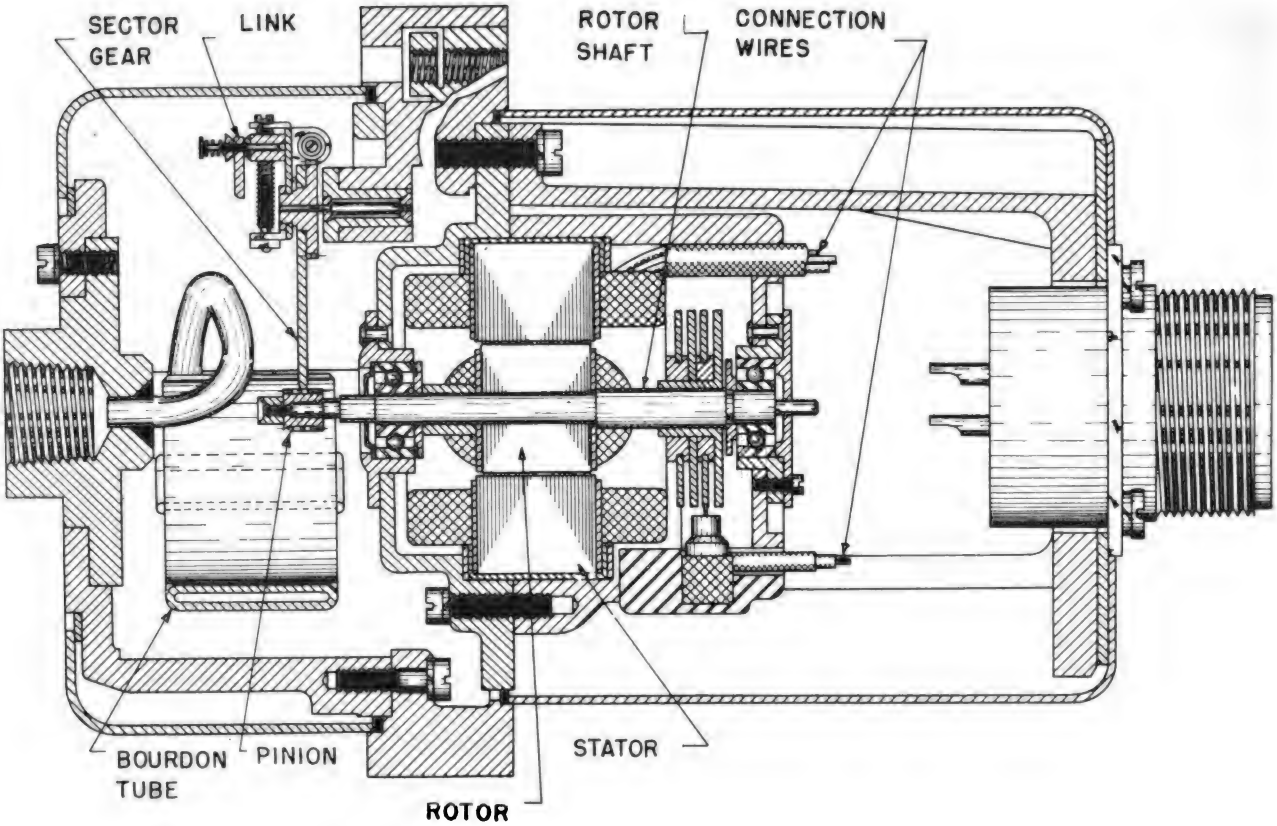


Figure 85. Cross-section of remote-indicating transmitter.

c. INDICATOR. (1) The indicator, which can be used with any kind of transmitter (provided the indicator dial is suitably marked), is connected electrically to the transmitter. The indicator consists mainly of a stator and rotor, a graduated dial, and a pointer. The motor assembly is the same as the transmitter motor assembly, except that the rotor contacts are of the brush type.

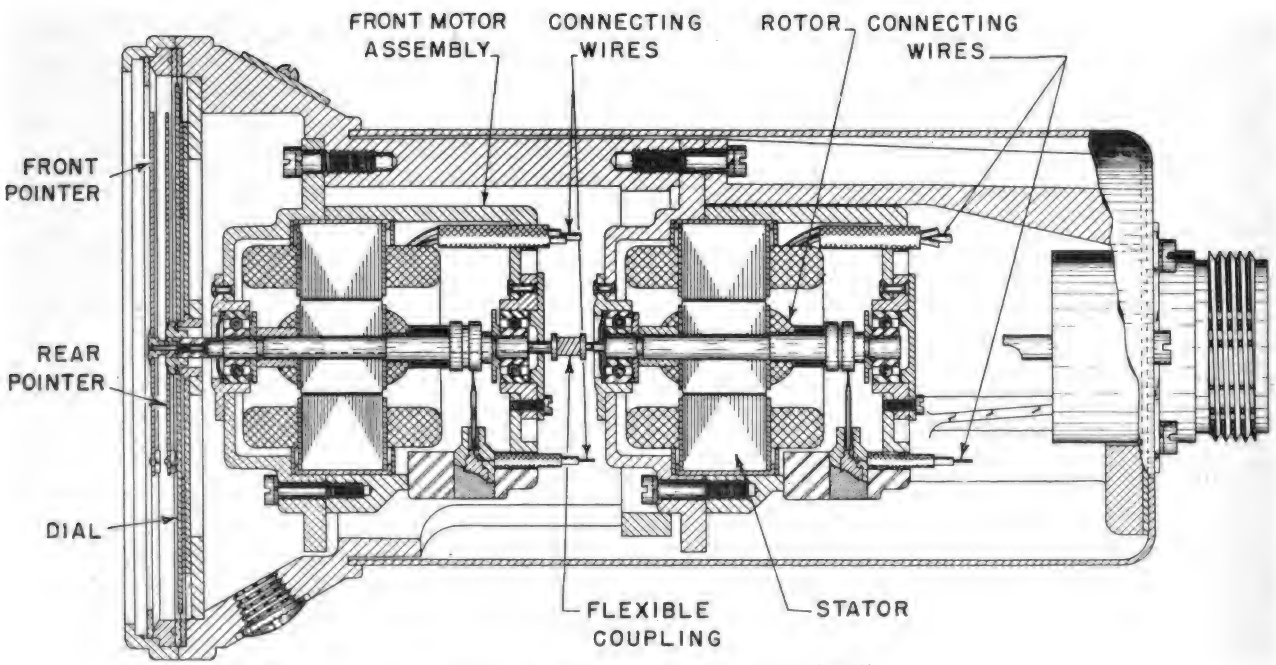


Figure 86. Remote-indicating indicator (dual).

(2) Where space is limited or the same functions of two engines are to be synchronized on the same dial a dual indicator, shown in figure 86, is used with two transmitters. The dual indicator includes two motor assemblies, mounted one behind the other, each with a pointer attached to its rotor. The pointers rotate about the same center and use the same dial. The hands are coded to indicate the engine with which each is associated. The rear motor operates the front pointer through the hollow shaft of the front rotor.

d. WIRING. (1) Older types of autosyn (a-c synchronous) instruments were designed for 32-volt, 60-cycle a-c power. However, the standard types most commonly in use are designed for 26 volts, 400 cycles. Voltages and frequencies up to 52 volts, 800 cycles, may be used on these latter models as long as the frequency is between 13 and 17 times the voltage.

(2) In the 32-volt, 60-cycle systems, connections are made to separate terminals (fig. 87). Transmitter terminals marked *1*, *2*, and *3*, are the stator connections and are connected to like terminals on the indicator. Terminals marked *A* and *G* are connected to the source of power. Terminal *G* is grounded internally. Some transmitters are equipped with a low-level or low-pressure warning system, and for this a terminal marked *W* is provided. This terminal connects to a warning light on the instrument panel.

(3) The 26-volt, 400-cycle instruments are much smaller and are equipped with AN standard electrical connections. Transmitters and single indicators have four-prong connectors. Dual indicators have seven-prong connectors. Figure 88 shows the method of wiring this system.

e. OPERATION. Power for operation of the system may be supplied by an engine-driven alternator or converted from direct current by a rotary- or vibrator type inverter. Power is applied to the rotors of both transmitter and indicator and sets up alternating magnetic fields in each. As these fields build up and collapse, they cut across the stator windings and set up induced voltages between the stator terminals. When the transmitter and indicator rotors are in identical positions, the voltages between like terminals are equal in the two stators, and when the stator terminals are properly connected the voltages are in opposition (cancel out) and no current flows. When one of the rotors is displaced, the voltages between like terminals are unequal, and current flows in the stator windings. This current produces forces

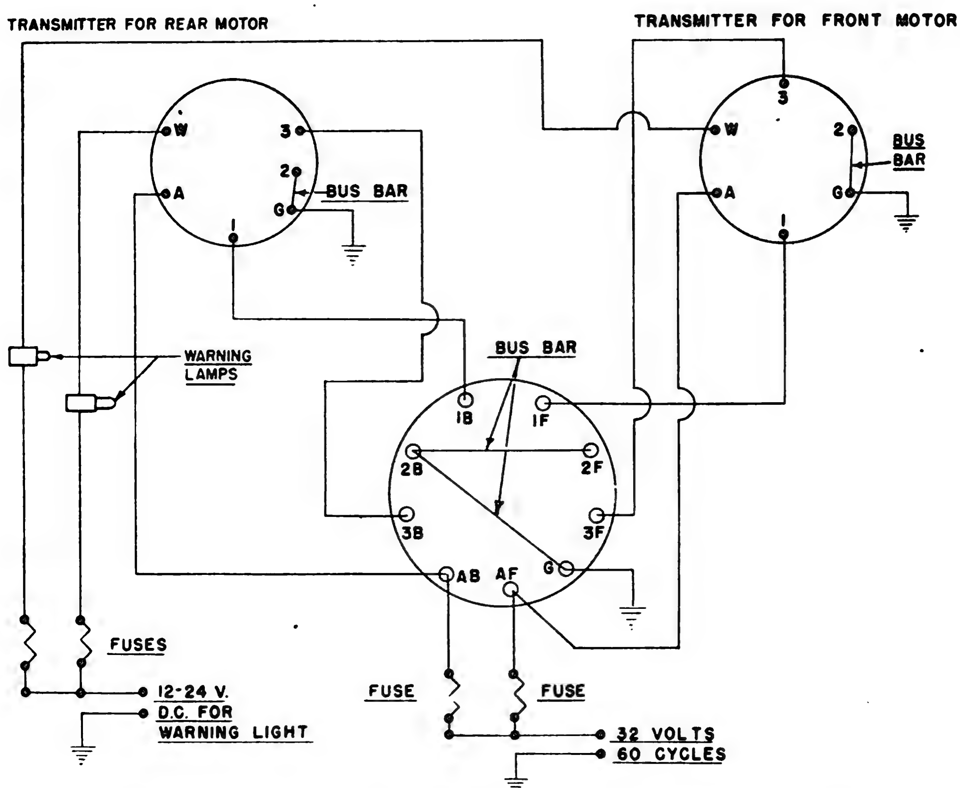


Figure 87. Wiring diagram for 32-volt, 60-cycle, a-c remote-indicating system.

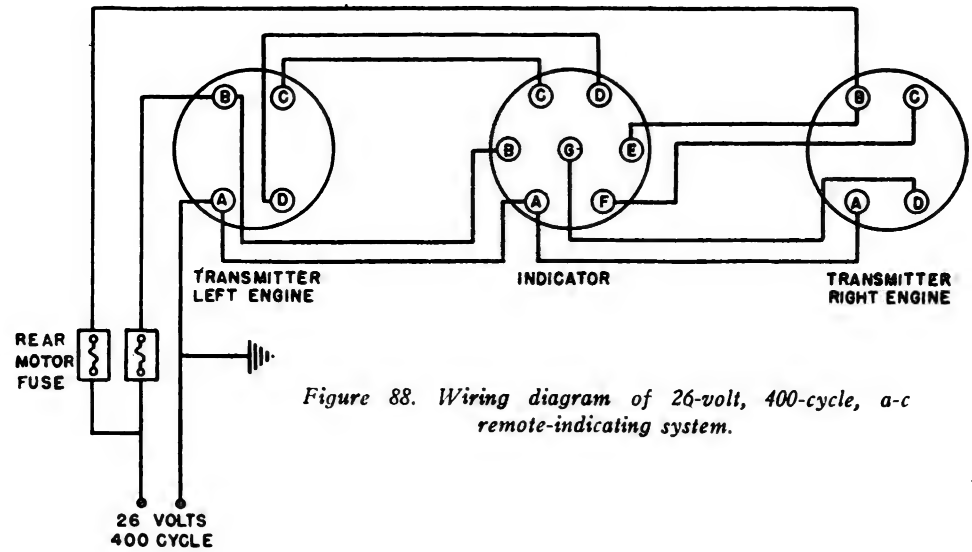


Figure 88. Wiring diagram of 26-volt, 400-cycle, a-c remote-indicating system.

in each rotor that tend to turn it toward the position of the other, but the position of the transmitter rotor is determined by the measuring mechanism. Hence the indicator rotor, which is free to rotate, must turn to a corresponding position. The pointer, being attached to the indicator rotor, thus moves to a location on the dial which indicates the value being measured or the position being registered.

f. Installation. Detailed instructions for the installation of particular systems are given in Technical Orders. Transmitters are mounted on shock-absorbing panels as near as possible to the point of measurement. For engine instruments the location is in the engine nacelle. Connections between the units are made with the sizes of wire specified in Technical Orders. The leads are soldered to the removable AN standard plugs.

32. Synchronous Direct-Current Instruments

a. General. (1) The d-c remote-indicating system is used for indicating fuel level in fuel tanks, gun-ammunition supply, or the position of movable parts of the airplane structure. Its main parts are the transmitter with the measuring mechanism, the indicator, and connecting leads. One to four transmitters are used with each indicator, or one or more indicators for each transmitter, depending upon the application of the instrument. Indicators used for certain purposes (such as indicating landing-gear positions) have two or more pointers, actuated by two or more motors, so that multiple functions can be registered by one indicator assembly.

(2) The instrument operates on either of two basic operating systems. One, known as the three-wire system, shown in figure 89, involves three leads between indicator and transmitter. The two-wire system (fig. 90) includes only two leads and a ground circuit. The circuits of the two systems differ, and the units are not interchangeable.

b. Three-wire System. (1) In the three-wire system, the transmitter (fig. 91) consists essentially of the following: a circular resistance winding, on which a pair of brushes (insulated from each other) operate, and a driveshaft actuated by linkage attached to a movable part of the airplane structure or to the fuel or ammunition measuring mechanism. The winding is tapped in three places for electrical connection to the indicator. The brushes are connected to the d-c battery supply. As the brushes are rotated by the driveshaft, which is turned by the action of the measuring or position-registering mechanism, the voltage at the taps of the winding is varied and a proportional variation occurs in the current flowing through the field coils of the indicator.

(2) The indicator (fig. 92) consists essentially of a core, three coils, and rotor. The core is made of a magnetic material; the three coils, connected in series, are placed on it at intervals of 120°. The leads between the coils are connected to the three taps of the transmitter winding. As the voltage at the transmitter taps is varied, the distribution of current in the indicator coils is affected, and the direction of the magnetic field is changed. As the magnetic field changes direction, the magnetized rotor follows it. Thus the pointer attached to the indicator rotor provides the desired indication on the dial.

(3) In the three-wire system, the whole transmitter coil is utilized. The three taps in the coil are evenly spaced. The three coils of the indicator are likewise evenly spaced around the circular core.

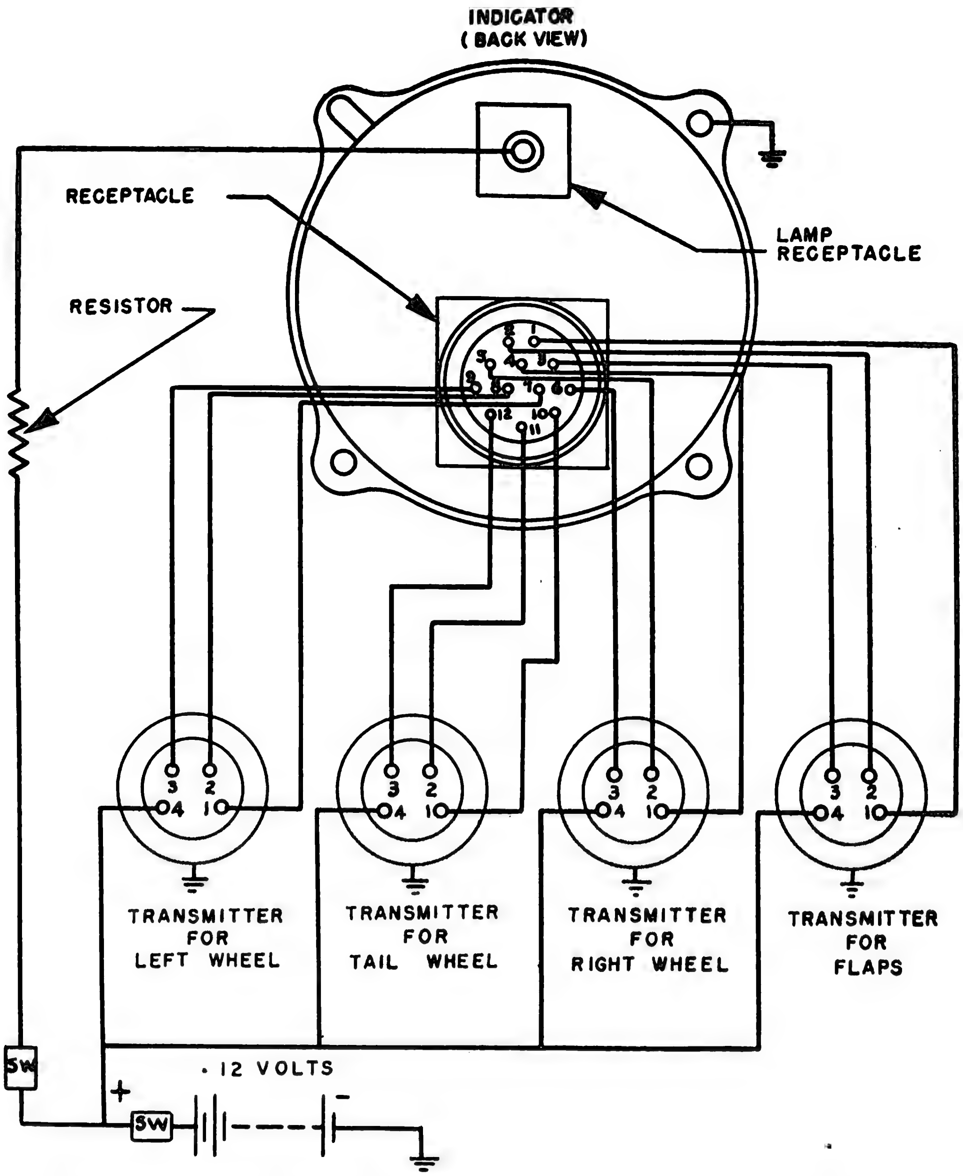


Figure 89. Wiring diagram for three-wire synchronous direct current system.

Because of these symmetrical characteristics between the transmitter and the indicator, the correspondence in movement between the transmitter brushes and the indicator rotor is inherently close.

c. Two-wire System. The transmitter used in the two-wire system has a single brush operating on the resistance winding. The indicator has two coils placed 120° apart on the core. (See fig. 93.) The battery is connected across two taps made in the transmitter winding and also across the two ends of the indicator coils. The indication is limited to a maximum of 90°. The two-wire system requires fewer connections than the three-wire system and is especially suitable for installations involving a pointer movement of 90° or less.

d. Operation. Synchronous d-c instruments are designed to operate on either 12- or 24-volt d-c power. A switch control in the cockpit governs the indicators. The word "Off" appears on the indicator of some instruments when the power supply is turned off or fails. When the power supply is off, a small, bar magnet in the indicator draws the pointer off the scale. When the position-indicating instrument is operating, the pointers in the indicator take positions according to the positions of the movable structural parts to which they correspond. The gear-locking switches are wired into the system of landing-gear position-indicating instruments, and as long as the landing-gear units are not locked, a warning flag is visible in the indicator or a light on the

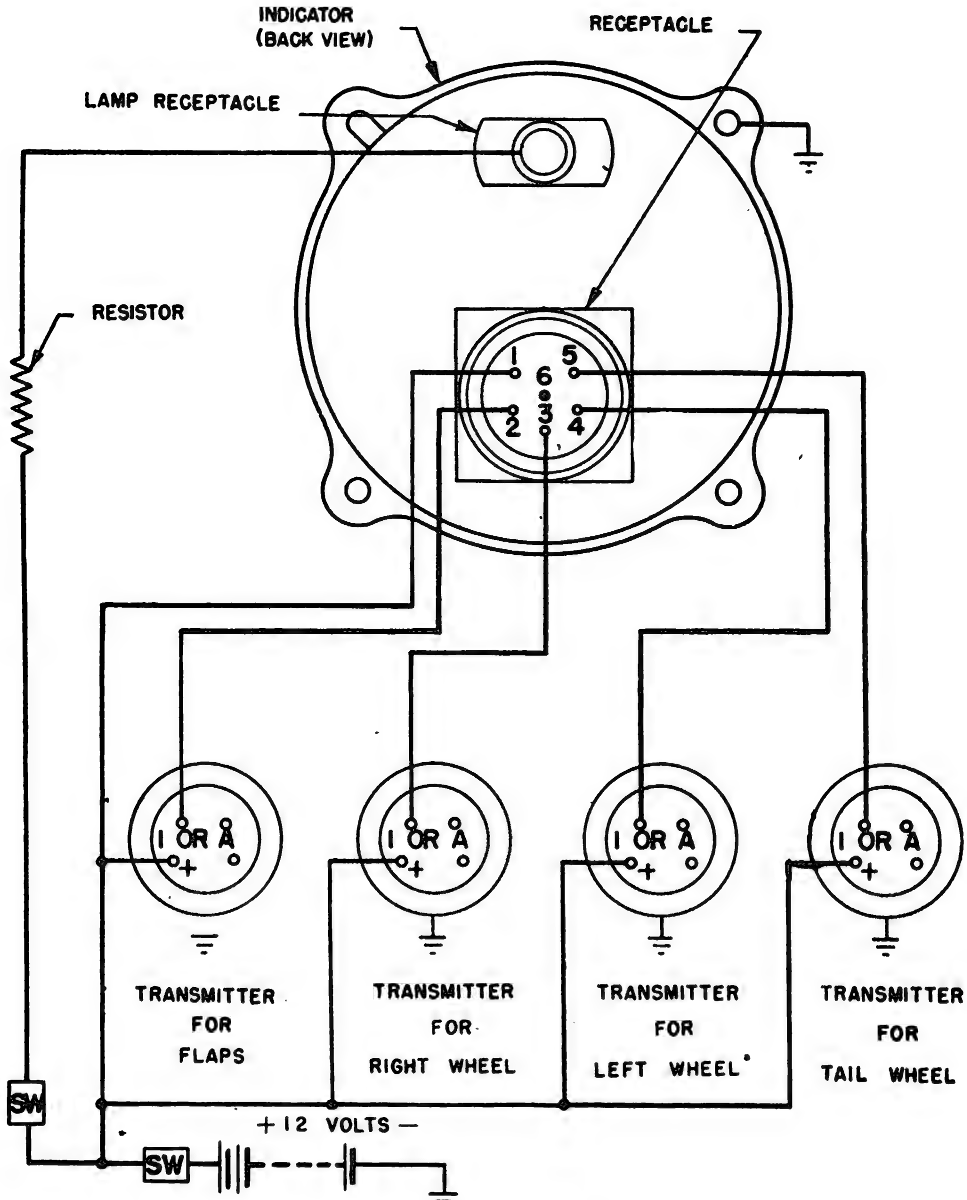


Figure 90. Wiring diagram for two-wire synchronous direct-current system.

indicator (used in some installations) remains off. On the indicators of fuel-level gauges, the contents of the various tanks are shown by the corresponding pointers.

e. INSTALLATION. Detailed instructions for installation are given in Technical Orders. The following instructions are general only.

(1) As already indicated, several transmitters may be used with one multiple type indicator, or more than one indicator with one transmitter, depending on the purpose of the particular installation. One complete instrument assembly consists of one indicator and one or more transmitters. The length of the leads between indicator and transmitter has no effect on the indicator readings.

(2) The transmitters are mounted on suitable brackets and are so located that the movable parts whose positions are to be registered can be mechanically linked to the transmitter shaft. The linkage can be made to rotate through approximately the same angle as that traveled by the indicator pointer. Transmitters for fuel-level gauges are mounted on the top or side of the tank and *are inserted* into the tank through openings made for this purpose. Before inserting the transmitter, be sure that the tank is empty and that the float or float arm does no strike any baffle in the tank.

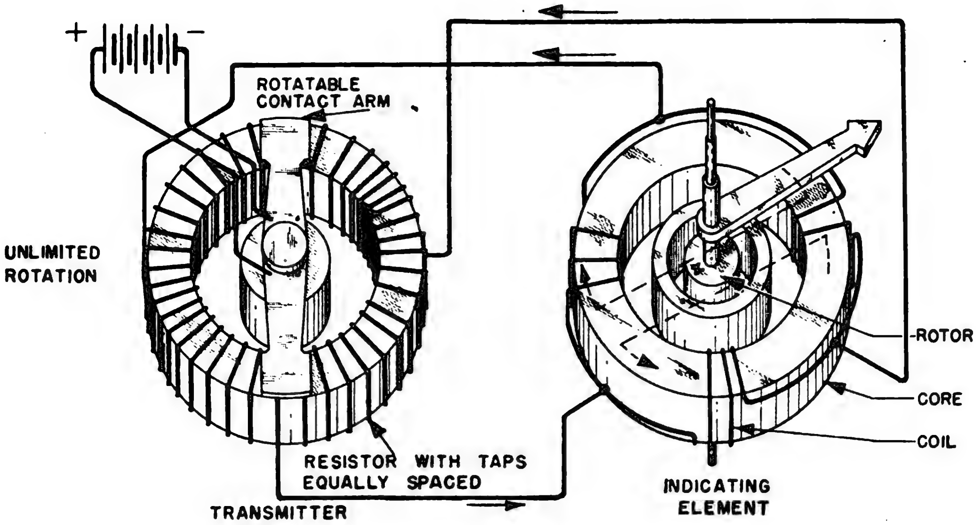


Figure 91. Schematic diagram—three-wire direct-current system.

① *Indicator.*

② *Transmitter.*

Figure 92. Position transmitter and indicator.

(3) In making connections from the power source through the transmitter to the indicator, care must be taken to prevent a short circuit in the external leads. A short circuit may cause the windings of the transmitter to burn out. Indicators equipped with lamps require the use of an external resistor in the lamp circuit to limit the current. The value of the resistor may be varied to obtain an intensity of illumination which will match that of the other instruments mounted on the same panel.

33. Inspection and Maintenance

a. A-c SYSTEMS. Before attempting any repairs or replacements with synchronous a-c instruments, it must be ascertained that the wiring and all external connections, including the plug contacts, are correct and in good condition. These are the most common sources of difficulty. The continuity or wiring should be carefully checked with a continuity tester. With the units properly connected and the instruments' power supply turned on, the indicator errors should be within the same limits as those of the instruments they replace. When it is definitely established that all wiring is correct, and the disconnect plug is properly assembled, it should be determined whether the mechanical connections to the engine or other mechanisms are correct and in good condition. The indicator or the transmitter may be faulty. The trouble should be isolated by using a master transmitter. Another indicator, with the cover glass removed, may be used as a master transmitter. Move the pointer manually and observe whether the test-indicator pointer follows the transmitter pointer. If an adjustment must be made in the internal mechanisms of a

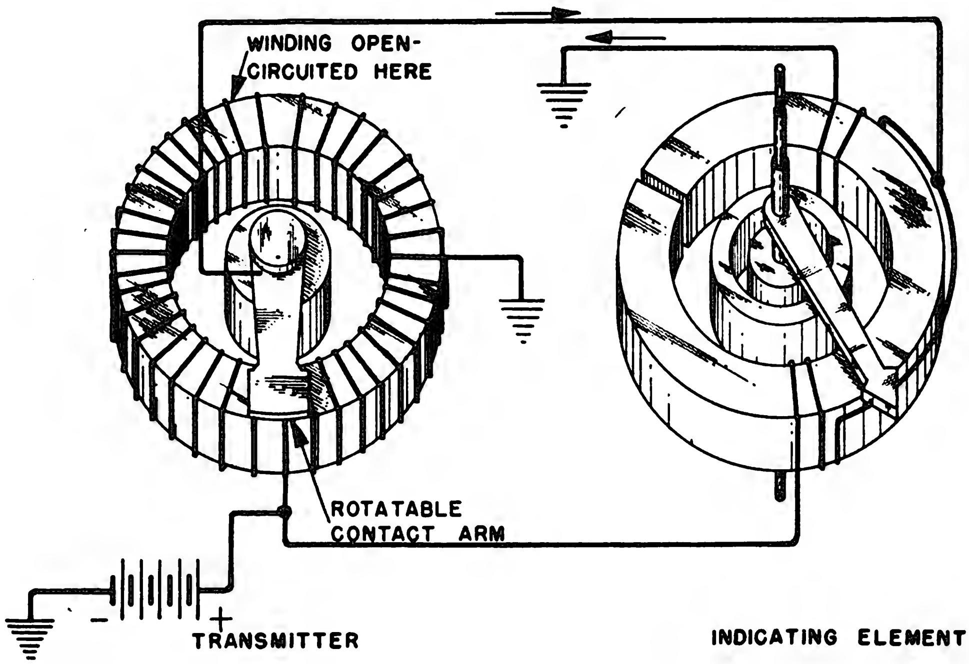


Figure 93. Schematic diagram for two-wire direct-current system.

unit, the faulty unit should be removed from the airplane and forwarded to the overhaul depot. No lubrication is necessary except at depots.

b. D-c Systems. Synchronous d-c instruments will be checked at regular intervals for the following:

(1) *Mechanical linkage.* The actuating linkage to the transmitter must be properly adjusted and securely attached.

(2) *Transmitter.* The operation of the transmitter may be checked by connecting it to an indicator known to be in good working order. If the indicator pointer moves continuously in one direction as the transmitter shaft is rotated continuously in one direction, the operation of the transmitter is correct. If the indicator pointer hesitates or momentarily moves backward, there is a poor connection in the transmitter. In this case, disassemble the transmitter, clean the contact surfaces and adjust the brush and contact tensions as directed in Technical Orders. If the transmitter coil or brushes are badly worn, the instrument assembly should be sent to a repair depot for overhaul. If the transmitter coil is burned out, the external circuit should be checked and any faults corrected before a new assembly is installed.

(3) *Indicator.* The indicator may be checked for lag or sluggish operation by turning on the power switch and noting the action of the pointers. They should snap into position without appearing sticky or showing signs of lag; if they do not, the indicator should be removed and sent to a repair depot for cleaning or overhaul.

(4) *Lubrication.* The flange bearing on the transmitter-element assembly should be lubricated with a few drops of light machine oil once a year. The indicator requires no lubrication.

SECTION VIII
AIRCRAFT COMPASSES (MAGNETIC)

34. General

a. The compass is a necessary navigation instrument for cross-country flying, patrol work, bombing expeditions, aerial photography, etc. Its principal function is to indicate the direction in which the plane is headed during flight on a straight course.

b. Magnetic compasses for aircraft use are of three general types:

(1) The pilot's (type B) compass: a direct-reading compass designed for instrument panel mounting.

(2) The navigator's (type D) compass: a direct-reading aperiodic compass designed for floor or table mounting.

(3) A remote-indicating compass which permits the magnetic element of the compass to be located at a point where the magnetic influences of the airplane structure or wiring system are at a minimum. As many as three indicators may be used with only one magnetic element, and may be located for use by the pilot, navigator, bombardier, etc.

35. Principles of Operation

a. If a bar magnet is mounted on a pivot, so that it is free to rotate in a horizontal plane, it will assume a position with one of its ends pointing toward the earth's north magnetic pole. This end of the magnet is called the north-seeking, or simply the north (N) pole of the magnet.

b. A magnetic compass for use in aircraft consists basically of a liquid-filled bowl containing a pivoted float element to which is fastened one or more bar magnets. The liquid in the bowl dampens the oscillations of the float and decreases the friction of the pivot. An expansion chamber is built into the compass to provide for expansion and contraction of the liquid resulting from altitude and temperature changes. If more than one magnet is used, they are mounted parallel to each other with like poles pointing in the same direction. The element is so suspended that the magnets are free to align themselves with the earth's north and south magnetic poles. Some means, such as a graduated card, is provided for indicating the north (N) pole of the magnets.

36. Applications

a. Pilot's (Type B) Compass. In the pilot's compass, shown in figures 94 and 95, a graduated card, called a "compass card," is attached to the float element. The card may be graduated in 1 or 5° increments. The 1° graduations are intended for use in larger airplanes or where the compass is required by the pilot for accurate navigation purposes. A fixed reference marker, called a "lubber line," is attached to the compass bowl. The lubber line and the graduations on the card are visible through a glass window. The magnetic heading of the airplane is read by noting on what graduation the lubber line falls. To correct for deviations of the magnetic element, which result from the magnetic influences of the airplane structure and electrical system, a compensating device containing small permanent magnets is incorporated in the compass. Two screws on the face of the instruments are used to move these magnets and thus counterbalance the local magnetic influences acting upon the card magnets. The pilot's compass indicates the magnetic heading of the airplane continuously, and does not require setting by the pilot.

Figure 94. Type B pilot's compass.

b. Navigator's (Type D) Compass. The compass card, used with the navigator's compass (fig. 96 and fig. 97), is graduated in 90° increments (N, E, S, and W). The card is equipped with radial arms and damping vanes which serve to increase the damping of the card movement in the liquid. This damping makes the compass aperiodic; that is, the card, after it has been deflected from a heading,

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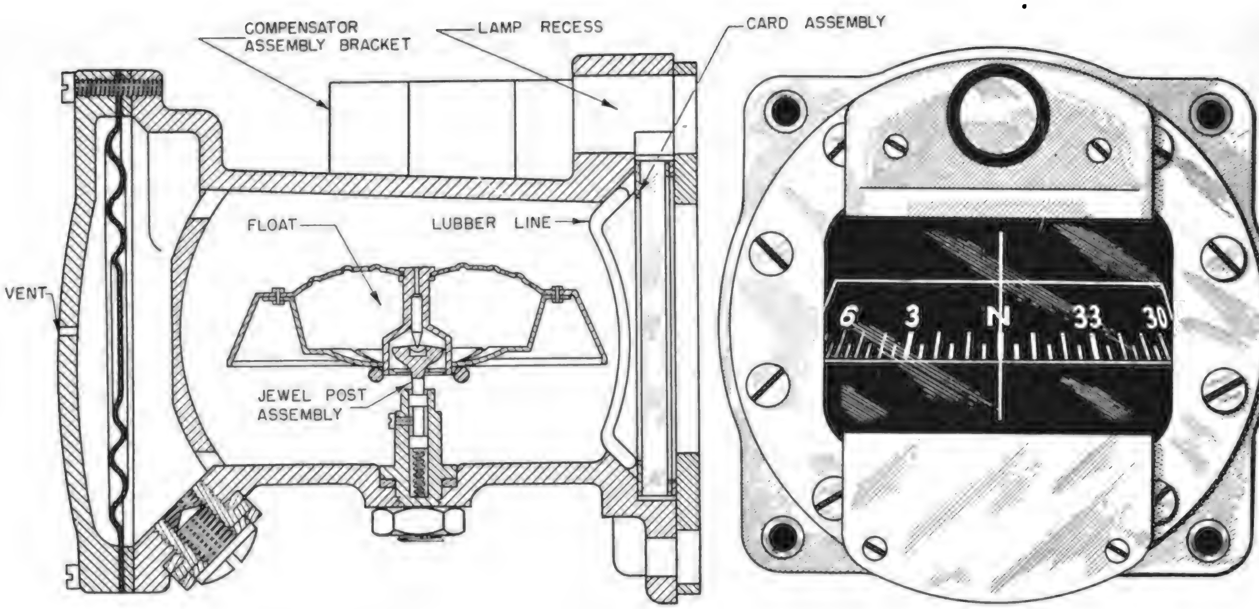

Figure 95. B type pilot's compass.

Figure 96. Type D navigator's compass.

returns to the north-pointing position in one direct movement or makes but one or two overswings. A lubber line is fixed to the compass bowl. A verge ring, mounted on the compass bowl, is calibrated in 1- or 2-° increments from 0° to 360°. Fixed to the verge ring are two parallel grid wires. The verge ring is so constructed that it may be rotated to bring the grid wires into alignment with the N-S line on the compass card. When the grid wires are set parallel to the N-S line on the compass card, the magnetic heading of the airplane may be read by viewing the graduations on the verge wing with respect to the lubber line. A small box, with drilled holes, on the bottom of the instrument provides room for loose magnets which make up the compensation system.

c. Remote-reading Magnetic Compass. The instrument panel of a modern airplane is a poor location for the ordinary magnetic compass because of the strong magnetic fields created there by the wide use of steel, magnetic alloys, and direct-current electricity. These fields exert forces on the compass magnets which prevent the magnets from aligning accurately with the earth's magnetic field, and thus interfere with the operation of the instrument. To overcome this difficulty, the remote-indicating compass, shown in figures 98 and 99, was developed. It consists of two main assemblies; a transmitter and an indicator.

(1) The transmitter, in figure 98, containing the magnetically sensitive direction-seeking element, is located as far as possible from the engines, guns, turrets, and armor plate. The magnetic element is a permanently magnetized float assembly, immersed in a bowl completely filled with kerosene. Damping fins prevent excessive oscillation of the float. Expansion and contraction of the liquid are permitted by a diaphragm. Below the float is a ring of circular laminations upon which is wound a coil of wire. A compensating assembly is provided for neutralizing the effect upon the magnetic element of any magnetic field very near the transmitter.

(2) The indicating unit, in figure 99, contains a stationary coil (stator) wound in the same manner as the coil of the transmitter. The rotor is a permanent magnet supported in the center of the stator

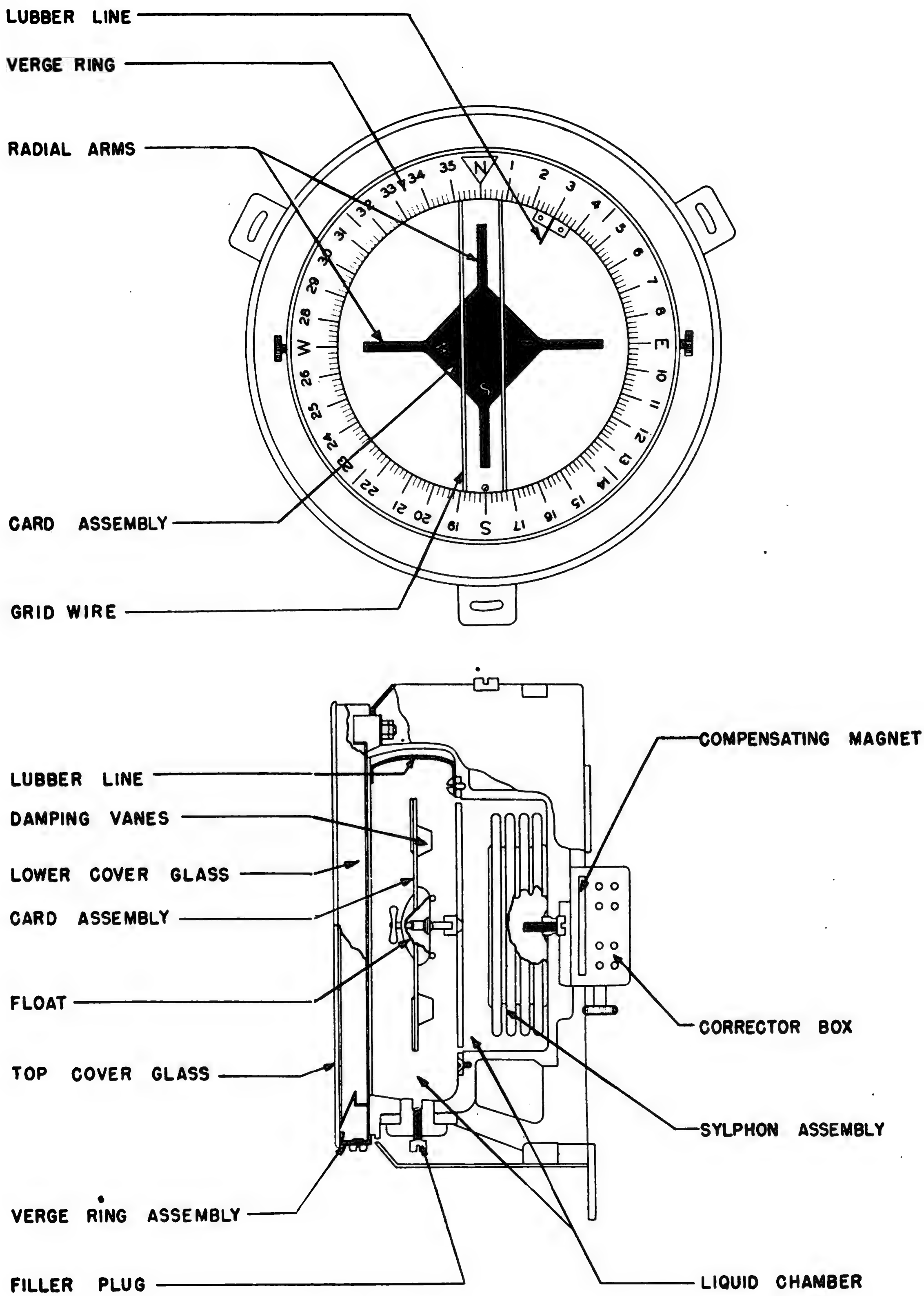

Figure 97. D type navigator's compass.

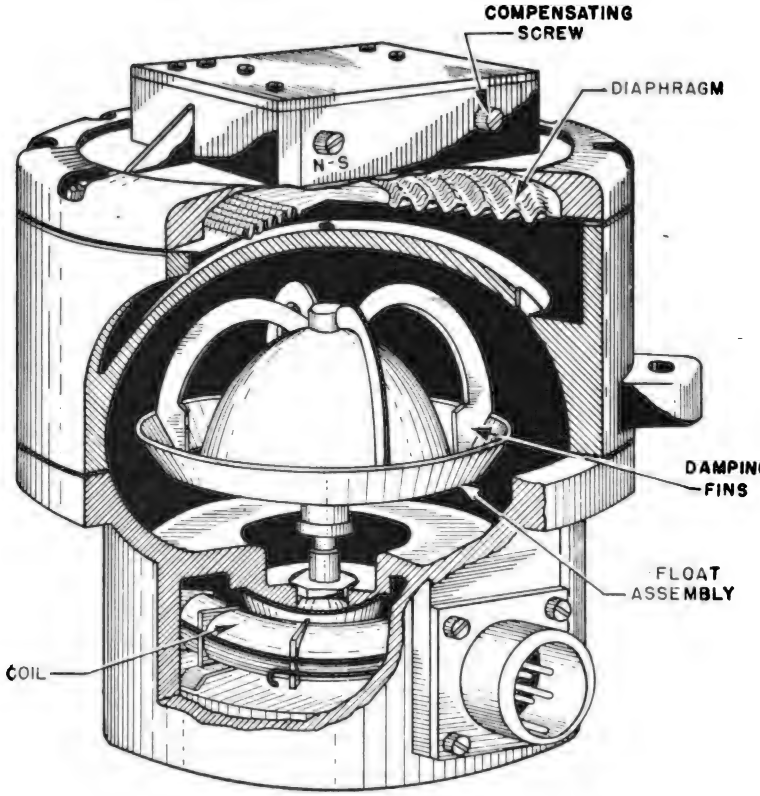

Figure 98. Remote-indicating compass transmitter.

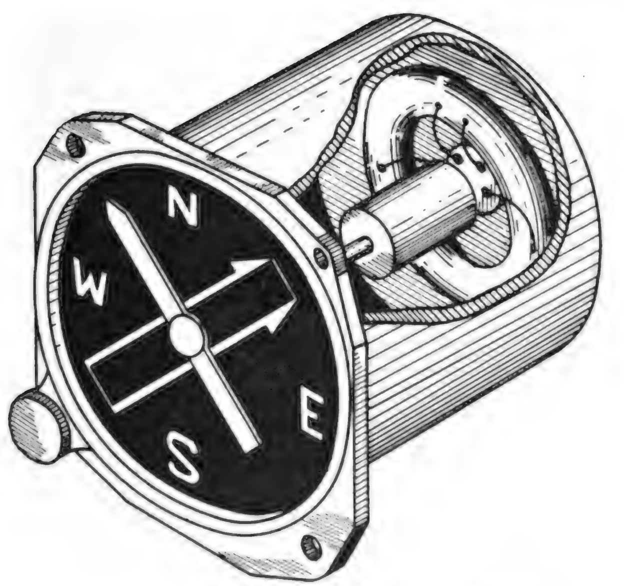

Figure 99. Remote-reading compass indicator.

by a shaft pivoted on jeweled bearings. A pointer is attached to the same shaft, and the entire rotor assembly is perfectly balanced to prevent position error. The dial is marked in 2° graduations. A course-reference marker which can be set by an external knob is provided for indicating the desired course.

(3) In operation, the permanent magnet of the transmitter aligns itself with the magnetic field of the earth. The position of this magnet above the transmitter coil distorts the magnetic field around the coil. This distortion is electrically transmitted to the stator of the indicator where it results in a similar magnetic field, so that the permanent magnet rotor of the indicator aligns itself in a position corresponding to the position of the transmitter rotor. The pointer, being attached to the shaft of the indicator rotor, thus shows the compass heading of the aircraft.

37. Magnetic Variation and Deviation

a. VARIATION. Magnetic "variation," which is caused by terrestrial (earth) magnetic influences, is the angular difference, in degrees, between the geographic north pole and the magnetic north pole. Since variation is due to the earth's magnetic field, which is constantly changing, and since variation differs in various localities, its effect on the compass cannot be removed by compensation. Variation is termed "west" variation when the earth's magnetic field draws the compass needle to the left of the geographic north pole; and "east" when the needle is drawn to the right.

b. Deviation. "Deviation," caused by the local magnetic influence of the aircraft in which the compass is mounted, is the angular difference in degrees between magnetic north and compass north. Although the deviation generally remains constant for only a short period, its effect on the compass can be removed by compensation. As with variation, deviation is termed "west" when the influence acting upon the compass needle draws it to the left of magnet north; and "east" when the needle is drawn to the right. It should be noted that deviation is the algebraic difference—magnetic heading minus compass heading—and is the correction which must be applied to compass heading to obtain magnetic heading. The algebraic difference (C-H)—(M-H) is commonly called "deviation correction" and is the correction which must be applied to magnetic heading to obtain compass heading.

c. Compass-correction Card. When a compass is compensated, or "swung" for deviation, a record of the procedure is made on the compass-correction card, AN 5803, shown in figure 100. The use of this card is explained in paragraph 38 in connection with the procedure for compensation.

38. Compensation

a. General. All compasses installed on aircraft are checked for accuracy, compensated if necessary, and the readings recorded on the compass correction card as follows: at the end of each period of 100 flying hours; at each engine change period; at the change of guns or electrical equipment likely to affect the compass; or at least once during each 3-month period. However, if at any time the compass is suspected of being in error, it should be checked and compensated. The process of compensating for deviations in compasses after installation in an aircraft—that is, offsetting within close limits the errors by local magnetic influences, and obtaining and recording the final deviations at the various points of the compass—is termed "swinging the compass." The compensation of compasses in-

	Compensating Swing			Residual Swing		Aircraft Comp.	Date	
	Actual Head (M)	Aircraft Comp.	Dev'n	Actual Head (M)	Aircraft Comp.	C to M		M to C
N 000	000	008	−8	000	002	−2	000	+2
NE 045				045	046	−1	045	+1
E 090	090	086	+4	090	092	−2	090	+2
SE 135				135	135	0	135	0
S 180	180	176	+4	180	182	−2	180	+2
SW 225				225	224	+1	225	−1
W 270	270	278	−8	270	272	−2	270	+2
NW315				315	315	0	315	0
	(1)	(2)	(1)–(2)	(3)	(4)	(3)–(4)		(4)–(3)

If swinging compass used ahead of aircraft add or subtract 180 degrees.

$$\text{Coeff. C} = \frac{N-S}{2} = \frac{(-8)-(+4)}{2} = \frac{-12}{2} = -6$$

$$\text{Coeff. B} = \frac{E-W}{2} = \frac{(+4)-(-8)}{2} = \frac{12}{2} = 6$$

$$\text{Coeff. A} = \frac{N+E+S+W}{4} = \frac{(-8)+(+4)+(+4)+(-8)}{4} = \frac{-8}{4} = -2$$

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Figure 100. Compass-correction card.

stalled in aircraft cannot be expected to remain accurate for very long periods of time, because under service conditions over a period of time, the magnetism of the aircraft structure is constantly changing in both intensity and direction.

b. Preliminary Instructions. The following instructions should be observed prior to the compensation of all magnetic aircraft compasses:

(1) See that the airplane is at least 100 yards from any steel structure, underground cables, metal pipes, or other aircraft.

(2) Make sure that all items in the airplane containing ferrous materials are located in the positions they will occupy during flight.

(3) Remove all compensating magnets from the compass prior to compensation. Keep all unused magnets at least 2 feet away from the compass.

(4) Remove all magnetic articles from one's person. Use a nonmagnetic screw driver.

(5) Using a small permanent magnet, cause the compass card to deflect through a small angle. Note whether the card rotates freely on its pivot, and that its path of rotation is in a horizontal plane. To avoid erroneous readings, read the pilot's compass only from a position directly in front of the lubber line and the navigator's compass from directly above the lubber line.

(6) Prior to compensation of the remote-reading magnetic compass, have the airplane headed successively toward magnetic north, east, south, and west with the engines operating. The indicator unit must read within 2° of the deviation noted on the correction card. If they read within the specified tolerance, the compass does not need compensating. If they do not, check the applied voltage. If the power supply is functioning properly, compensate the instrument.

(7) Check the compensating assembly (on top of the transmitter) of the remote-reading compass and the pilot's compass to be sure that the two white dots on the compensator screws are in line with the two white dots between the letters NS and EW on the compensator front plate. When these dots are aligned, the effect of the compensator on the compass element will be nullified. The possibility of damage to the compensator assembly, which would make this method of neutralization ineffective, should be kept in mind.

c. Compensating on a Compass Rose. A compass rose (fig. 101) is often used to obtain the necessary magnetic headings when an aircraft compass is being compensated. This method of swinging the compass is desirable provided that care is exercised in aligning the airplane with the various headings. The rose consists of a large circular concrete platform on which various required headings are clearly marked. All equipment used in the vicinity of the rose must be of nonmagnetic materials.

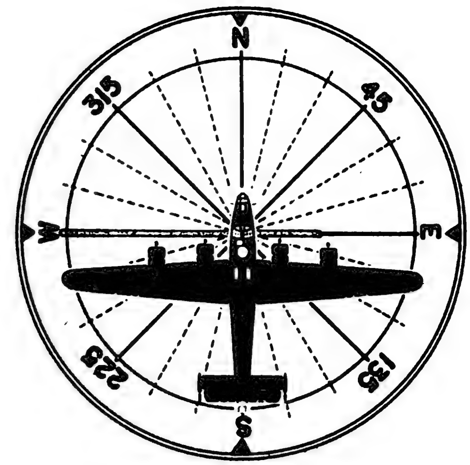


Figure 101. Compass rose.

(1) The first step in compensating a compass on a rose is to place the airplane on the compass rose and head it toward magnetic north. Then raise the tail of the airplane to the normal flying position. Turn on the power supply to the compass (if remote-reading type) and start the engines so that flight conditions are simulated as nearly as possible. For those direct reading compasses, which are intended for standby use only, all electrical circuits which may effect operation of the compass must be off and the deviation card so placarded. Record the compass reading in column 2, line 1, of the compass-correction card as shown in figure 100. Assume that the compass reading is 8°.

(2) Turn the airplane to the east magnetic heading and record the compass reading in column 2, line 3, of the compass-correction card. Assume that the reading is 86°.

(3) Turn the airplane to the south magnetic heading and record the compass reading in column 2, line 5, of the compass-correction card. Assume that the reading is 176°.

(4) Turn the airplane to the west magnetic heading and record the compass reading in column 2, line 7, of the compass-correction card. Assume that the compass reading is 278°.

(5) Fill in column headed "Dev'n," then compute coefficients A, B and C as indicated on the bottom of the compass-correction card, in figure 100. All additions and subtractions are algebraic.

(6) Return the airplane to the north magnetic heading (within 5° by its own compass). Add coefficient C algebraically to the compass reading on

that heading to determine what the compass should read when compensated. Adjust the N-S compensating screw (of polyplane compensator) or insert magnets in the compensating drawer, which is at right angles to the needle, until the compass indicates the compensated value.

(7) Head the airplane east (within 5° by its own compass). Add coefficient *B* algebraically to the compass reading on that heading. Adjust the E-W compensating screw (or insert magnets in that chamber of the compensating drawer at right angles to the needle) until the compass indicates the compensated value.

(8) Coefficient *A* represents the lubber line error and must be removed by rotating the compass bowl in the required direction, clockwise if *A* is a plus value and counterclockwise if it is a minus value. This can be done with the aircraft on any heading. Add coefficient *A* algebraically to the compass reading on that heading, then rotate the compass bowl until the compass indicates the compensated value. (When the pilot's compass is mounted on an instrument panel, the correction for coefficient *A* is impractical and may be omitted.)

(9) The residual swing can begin on any heading. Record the actual heading and compass reading in columns 3 and 4. Repeat every 45° around the circle. Then complete the form, subtracting as indicated at the bottom of the two blank columns. Fill in the back of the card. Detach the card and place it in the aircraft compass card holder. File the remainder of the form as directed by the organization engineering officer.

d. A Pioneer type B-16 compass may be used as a swinging compass in compass compensation. The compensating assembly is removed from the compass and a special sighting-device fitting is substituted. During the compensating procedure with this instrument, the aircraft is turned to the desired heading as indicated by the aircraft compass. A sight is then taken by the swinging compass, two points on the fore-and-aft axis of the airplane being lined up with the hair line in the collimator lens as shown in figure 102. The compass used for this purpose may be painted red indicating that it has been remagnetized 180° from normal. This permits the observer to read the magnetic heading of the aircraft directly when sighting from in front of the aircraft. If a compass drawn from stock is used as a swinging sight, 180° must be added to the compass reading to obtain the magnetic heading of the aircraft. Corrections, as indicated by the master compass, are made on each of the cardinal headings in the conventional manner. In every other respect the compensation is exactly the same as in the use of the compass rose.

e. The compass may be checked for deviation while flying by taking a bearing on a celestial or terrestrial object, the bearing of which is known.

39. Installation

a. General. (1) Installation of compasses by service activities should always be made in the location provided in the airplane unless relocation is found necessary and is authorized. Special attention should be given to the prevention of disturbing magnetic fields in the vicinity of the compass. Permanent fields may result from the proximity of electrical equipment, radio, armament, or structural members. Variable fields may result from variations

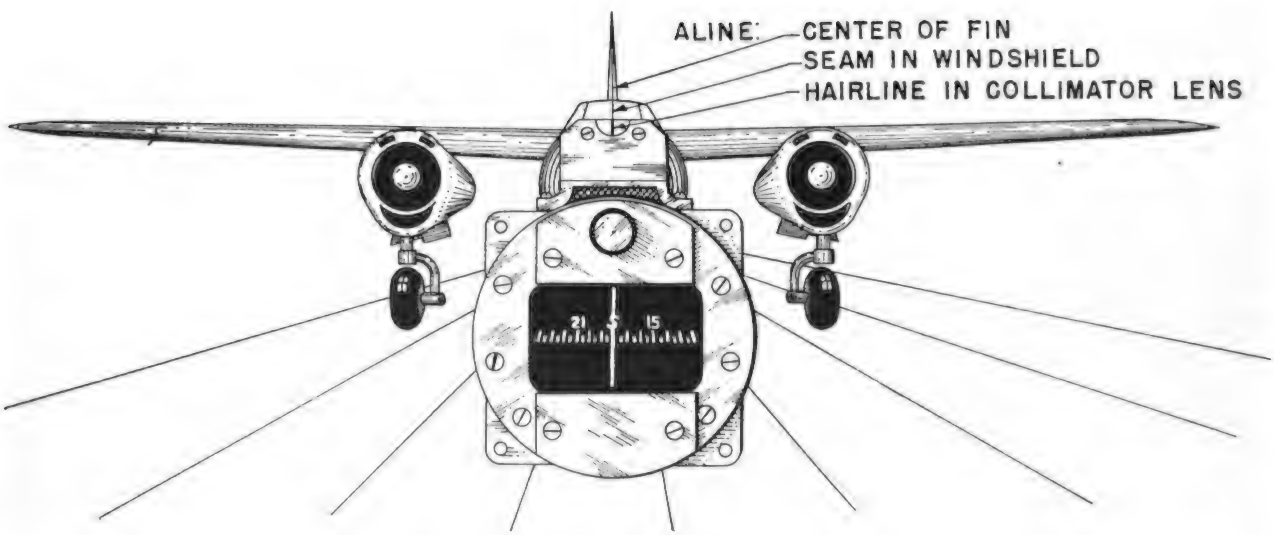


Figure 102. Alignment of airplane with swinging compass.

in current flow in electrical wiring or the position of retractable landing gear or like equipment. A reasonable amount of permanent magnetism in the vicinity of the compass can be compensated for, but variable magnetic fields cannot.

(2) Compasses are installed so that a vertical plane, passing through the card pivot and lubber line, will be parallel to the longitudinal axis of the airplane, and the card pivot-supporting post will be perpendicular to the horizontal plane when the airplane is in flying position.

(3) All compasses are so mounted that the compass compensating chamber and the adjusting screws will be easily accessible. Brackets required for mounting compasses shall be made of brass, duralumin, or other nonmagnetic materials. Mounting screws for compasses should be of brass.

b. Type B Compass. The pilot's compass is so constructed that the two conditions mentioned in foregoing paragraph 39*a*, (2) are fulfilled when the instrument panel upon which it is mounted is perpendicular to the longitudinal axis of the airplane.

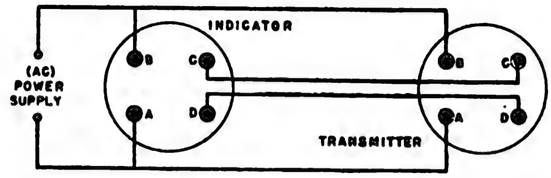
c. Type D Compass. The navigator's compass is so constructed that the two conditions mentioned in foregoing paragraph 39*a*, (2) are fulfilled when the surface of the base, upon which the compass is mounted, is parallel with the airplane leveling studs, and a vertical plane through the card pitot and lubber line of the compass is parallel to the longitudinal axis of the airplane.

d. Remote-reading Compass. The transmitter unit of the remote-reading compass is installed where there is a minimum of local magnetic interference, generally in the wing tip. It is advisable to install it as far as possible from all electrical wires and from moving steel structures such as gun turrets. It should be shock-mounted on a nonmagnetic platform, so that the plane of the mounting lugs is horizontal in normal level flight. A plane passing through the center of the disconnect-plug receptacle and the center of the rear mounting hole must be parallel to the fore-and-aft axis of the airplane. The small arrow on the top of the compass transmitter should be pointing forward.

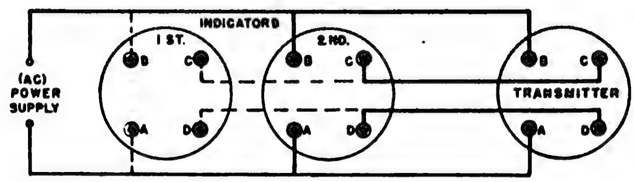
(1) The transmitter is checked for alignment before compensation. With the compensating magnets at neutral, the deviation (plus or minus) on the cardinal headings are added together and the result divided by four to give the average deviation. The transmitter is then rotated so that the reading on the indicator is decreased or increased by an amount equal to the average deviation.

(2) The compass indicators may be located on the instrument panel in any position best suited for observation purposes.

(3) The electrical system employs 26-volt, 400-cycle alternating current, which is obtained from the same source as that employed by the self-synchronous instruments or from an independent inverter. Standard wire of the correct size should be used for all electrical connections. Quarter-inch aluminum, braided, flexible conduit should be used for the immediate connection to the transmitter and indicator. Four-prong AN standard disconnect plugs are provided at both transmitters and indicators. Like lettered terminals, on the transmitter and the indicator, should be wired together (*A* to *A*, *B* to *B*, *C* to *C*, *D* to *D*), as shown in figure 103. The *A* and *B* terminals are the power-supply terminals.



① *One indicator.*



② *Two indicators.*

Figure 103. Wiring diagram—remote-indicating compass.

40. Inspection and Maintenance

a. Normal Maintenance. Normal service or line maintenance for aircraft compasses consists of the replacement of defective lamps, checking the lighting system for defective electrical connections, compensation, and replacement of defective compasses. Remove compasses and replace with serviceable instruments if any of the following conditions exist.

(1) Clouded or discolored liquid which impairs visibility.

(2) Illegible card markings, due to discoloration, fading, or loss of luminous paint.

(3) Failure of card to rotate freely in a horizontal plane when the airplane is in normal flying condition. Rotation may be checked by deflecting the card with a small permanent magnet.

(4) Cracked bowl; broken mounting frame or lugs.

(5) Failure of compass to respond, or erratic action, after proper efforts to compensate.

(6) Lubber line loose or misaligned.

(7) Bench test, disassembly, or additional liquid required; any other major defects which might render the compass inoperative.

b. Causes of Inaccuracy. There are five main causes for inaccuracy in aircraft compasses:

(1) *Incorrect installation.* By careful selection of the compass location, aircraft and instrument designers generally reduce or eliminate compass inaccuracies due to faulty installation.

(2) *Vibration.* Errors due to vibration can be satisfactorily eliminated by the use of vibration absorption panels or proper vibration insulating mounts.

(3) *Magnetism.* During the construction of air craft, the vibration and jarring of steel parts while they are being forged, machined, or fitted in place create a certain amount of permanent magnetism which is induced by the earth's magnetic field. This permanent magnetism will vary with vibration of the engine, shocks from gunfire, landings, etc. This changing field of permanent magnetism correspondingly affects the action of the earth's magnetic field on the compass and thus causes the compass card to deviate from magnetic north. Further deviations of the compass result from electric currents flowing in the electrical system of the airçraft, radio equipment, electrical instruments, and varying positions of metallic masses such as bomb loads, retractable landing gear, etc. Corrections of compass errors resulting from the permanent magnetic influences referred to may, if not excessive, be accomplished within close limits by the proper use of compensating magnets.

(4) *Heeling error.* Ordinarily the vertical component of the aircraft's magnetic field has no effect on the compass readings, since it is at right angles to the compass card. However, when the aircraft is not in level flying position, this vertical component affects the compass card and produces a deviation known as "heeling error." Correction for this error is not necessary, because all compass readings, either during compensation or during flight, should be made only with the aircraft in level flying position.

(5) *"Northerly turning error."* One of the most serious errors of the aircraft compass occurs during any turn. It is strongest when turning from a northerly course. It is caused by the vertical component of the earth's magnetic field. If an aircraft is flying northward and executes a properly banked turn to the "east" or "west," the compass card, under the influence of centrifugal force, no longer remains horizontal but tips with the airplane and assumes a position parallel to the aircraft's floor. The card magnets then assume a position which is the result of their tendency to point north and their tendency to dip. The northerly turning error is evident in a small degree on all turns whenever the airplane is banked, but extreme cases occur in vertical banks on north headings. In clear weather, the pilot can use some fixed point on the ground for reference, and thus can straighten out his course and hold the aircraft level until he can obtain a steady compass reading. In cloudy weather, however, where the use of an outside reference point may be impossible, the pilot must use instruments to hold the aircraft level until he can obtain his reading.

c. Deviation Permitted. The maximum deviation on any heading before compensation of direct-reading compasses should not exceed 8°. After the deviations have been reduced by compensation, the maximum deviation on any heading should not exceed 2°. Deviation limits for remote-reading compasses are one-half those of direct-reading compasses. These requirements may differ in various localities according to differences in the earth's magnetic field. Many compasses now in use will not meet these requirements. If it is decided that the compass performance in a particular aircraft is faulty, an unsatisfactory report should be submitted. Data necessary for corrective measures should be submitted with the report. Such data should be obtained as follows:

(1) Remove the compass compensator assembly.

(2) Start the engines.

(3) Place the aircraft's head on magnetic north, and read the compass. Record both the compass reading and the actual magnetic heading of the aircraft.

(4) With engines idling, record the aircraft compass reading as each switch, except the generator, is operated in turn (radio, pitot heater, gunsight, cockpit heater, gun solenoids, landing navigation, instrument lights, etc.). Allow the compass time to settle before each reading.

(5) Run up the engine until the generator is charging, and turn on the generator switch. Record the compass reading.

(6) Repeat the foregoing steps on each magnetic heading of 45°.

(7) With the airplane in level cruising flight on each 45° heading, record the compass reading with wheels extended and wheels retracted.

d. Locating Source of Trouble. Before re-

turning a remote-indicating compass to the repair depot, determine whether the source of trouble is in the wiring, the indicator, or the transmitter. The wiring, which is responsible for most compass troubles, may be checked readily with an ohmmeter, and the trouble source thus isolated. An a-c voltmeter is useful for checking the power supply and leads. To determine whether the indicator or the transmitter is at fault, a master transmitter is used which has a pointer that can be rotated by hand. With the power of the compass system off, disco nect the plug of the installed transmitter. Conn the master transmitter to the disconnect plug on t cable. Switch on the power supply and manua turn the pointer of the master transmitter. If t indicator is observed to "follow" correctly and step with the master transmitter, the trouble sour is in the transmitter. If the indicator fails to f low correctly, the trouble is in the interconnecti cables or in the installed indicator.

SECTON IX
GYRO-STABILIZED FLUX-GATE COMPASS SYSTEM

41. General

The gyro-stabilized flux-gate compass system is remote indicating. The direction-sensitive element or transmitter can be placed in any part of the airplane where deviation and fluctuations in deviation are small. This unit is gyro stabilized so it will give true readings for all directions and for all climbing or diving angles of less than 65° from the horizontal. It has means of compensating for the variation between true and magnetic north and for deviations caused by magnetic materials in the airplane.

42. Description

a. Transmitter. The units of the transmitter, figure 104, are the flux-gate element, the erection

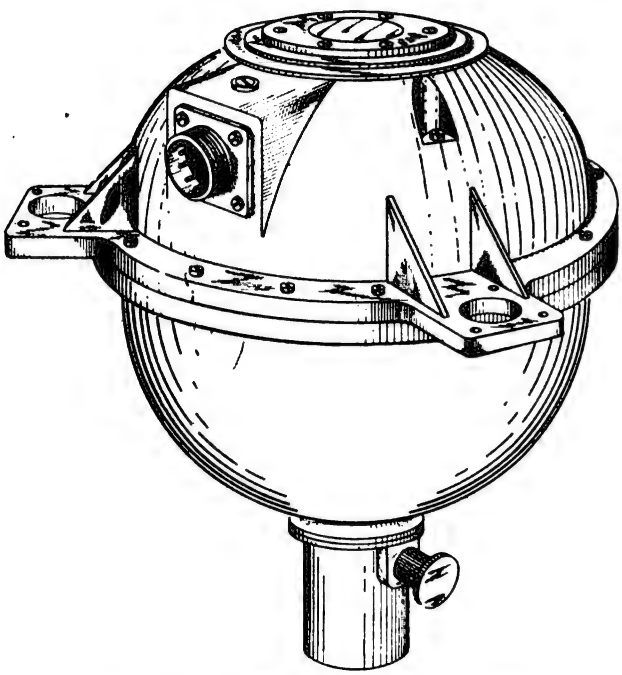


Figure 104. Transmitter—flux-gate compass.

mechanism, and a caging mechanism for the gyroscope, all mounted in a plastic housing.

(1) The flux-gate element is triangular in form, each leg consisting of two strips of magnetic metal with primary and secondary windings.

(*a*) The 487.5-cycle alternating current in the primary, produces magnetic saturation twice during each cycle. Twice each cycle, as the current falls to zero after each change of direction, the cores are saturated and subject to the earth's magnetic field. The primary winding is so arranged that th
of the primary current is cancelled insofa
would otherwise produce a current in the sec
winding. But the magnetic flux produced
primary acts as a "gate" to cut off the effect
earth's magnetic field each time the core is sa

(*b*) At the instant the cores are unsat
the earth's magnetic field induces a current
leg of the flux-gate. Thus, the circuit conne
each leg carries an alternating current with
quency of 975 cycles per second. The amo
current in each circuit depends upon the pos
the leg in relation to the earth's field. Lead
the three currents from the flux gate to an in
at the navigator's instrument panel. The
strengths of the three currents control the p
of the needle on the indicator. Repeater indic
other stations may be connected to the
indicator.

(2) *Erection mechanism.* A motor-drive
scope with a speed of 10,500 rpm is used to h
flux-gate horizontal during all maneuvers
the limits specified in preceding paragra
Precession of this gyroscope is prevented a
unit is held in the vertical position by the ac
a small steel ball which runs in a circular ste
above the gyroscope. As long as the unit i
the ball runs at a constant rate but at any
the track tilts also and the ball remains for a
time during each revolution on the uphill side
force tends to precess the gyro to a vertical p

(3) *Caging mechanism.* A small arm in t
tom of the transmitter housing may be ra
engage a pin in the bottom of the gyro housing
erects the gyro to vertical with respect to the
mitter housing. Allow the gyro to run 5 r
before performing this operation. In actual p
the gyro is never left in the caged position.

b. Amplifier. The 3 minute currents fr
flux-gate are combined in the coupling a
shown in figure 105, to give a voltage signal
is amplified by means of a five-tube amplifier
fig. 106.) This provides sufficient energy to
the induction motor which actuates the in
needle. This unit also includes an extremely
control-frequency oscillator to furnish power
flux gate. The oscillator output has a freque
487.5 cycles per second.

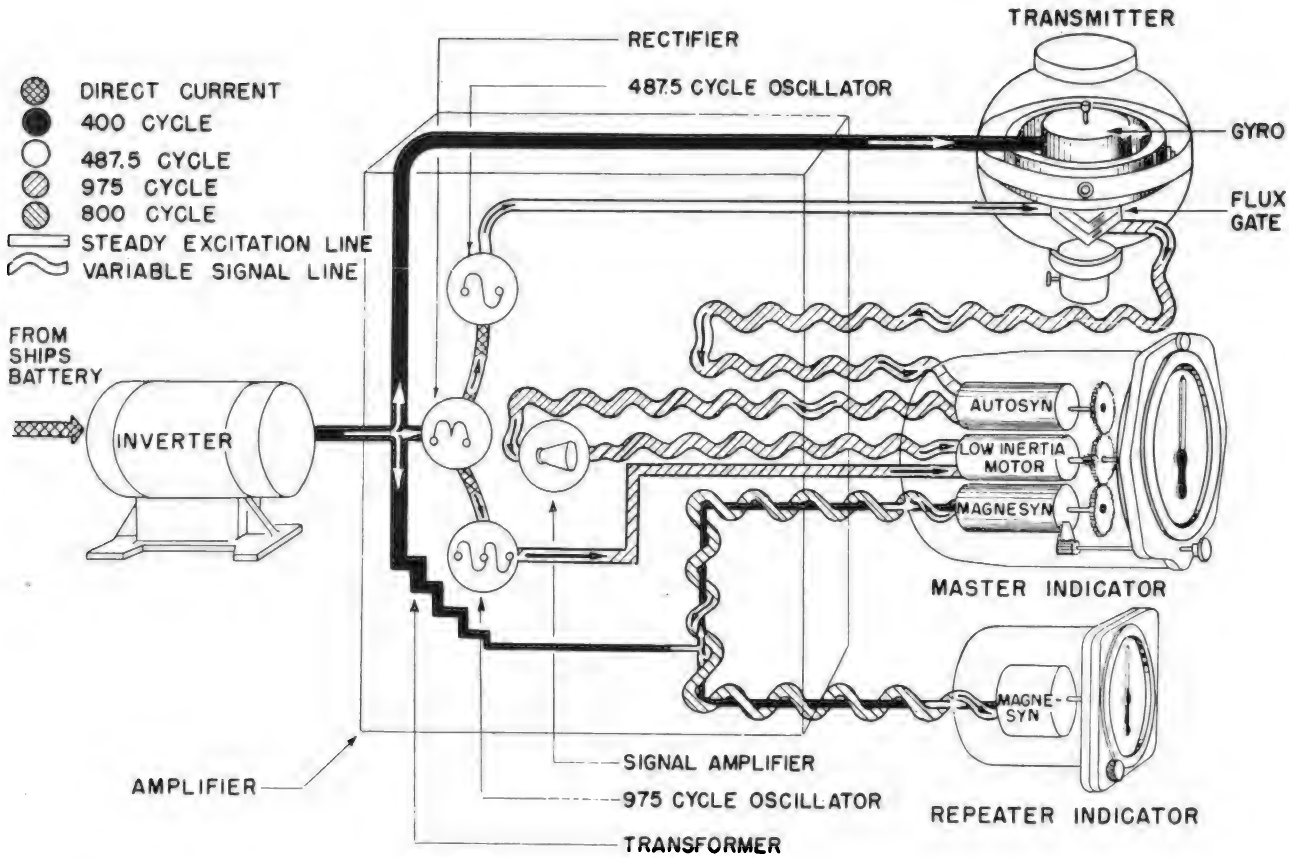


Figure 105. Gyro-stabilized flux-gate compass (schematic drawing).

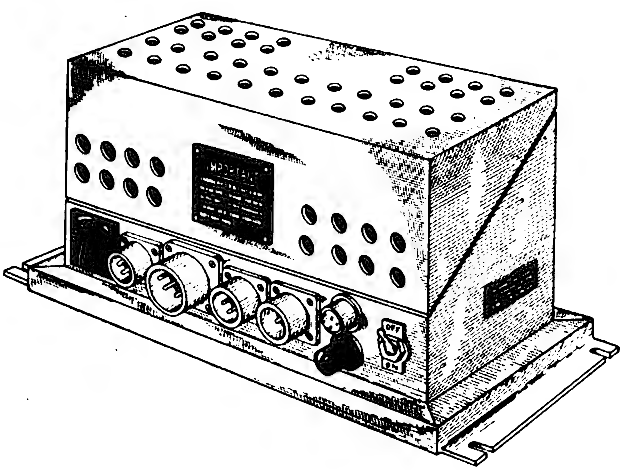


Figure 106. Amplifier—flux-gate compass.

c. INDICATORS. (1) The three currents from flux gate thus cause the induction motor to move the pointer to the position on the indicator dial which corresponds to the direction the airplane is facing.

(2) An uncorrected dial, visible in the face of the master indicator, as shown in figure 107, gives the uncorrected heading of the airplane at all times.

(3) The compensation mechanism causes the pointer to lag behind or to lead the uncorrected reading as the airplane is turned about the vertical axis. Compensating adjustment can be made each 15° or at 24 stations, and may correct for magnetic deviation up to 18° either way.

(4) The outer dial on the master indicator may be offset to correct for magnetic variations. A knob turns the dial until its South index coincides with the desired number of degrees correction as indicated on the "variation" dial.

(5) Corrections for deviation and variation are passed on to all repeater indicators (fig. 108) in other parts of the airplane, but, because of inherent transmission errors, correction cards are provided at each repeater.

d. INVERTER. When a 400-cycle alternating current is not otherwise provided, an inverter, shown in figure 109, drawing approximately 90 watts, is operated by power from a 24-volt source. The output is 115 volts at 400 cycles. This supplies all the current needed for the gyro stabilizer of the flux-gate system.

43. Installation

a. GENERAL. No unit of the flux-gate compass system (fig. 110) will be installed where vibration

Figure 107. Master-indicator flux-gate compass.

Figure 108. Repeater indicator—flux-gate compass.

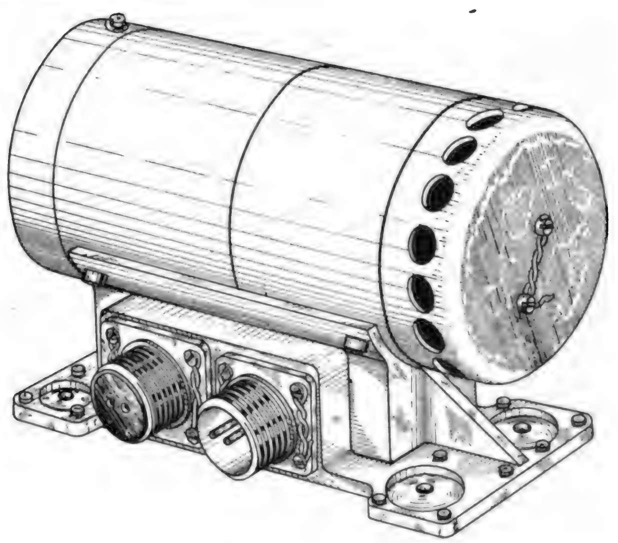


Figure 109. Inverter—flux-gate compass.

is excessive or where the surrounding temperature will exceed the values given in Technical Orders. Vibration insulating mounts are provided for all units. Double mounts are provided on the transmitter.

b. Transmitter. (1) Although the transmitter is mounted inside a molded plastic case and is well protected against dust, oil, etc., it has a small ventilator at the top and must not be placed where moisture or other foreign matter can enter. It must be mounted as far as possible from magnetic metals and especially from moving magnetic parts or variable loads. The final deviation due to these causes should be as small as possible and in no case should its value for any heading exceed that given in Technical Orders.

(2) The disconnect plug must be toward the front, and the caging head on the bottom. The "fore" and "aft" center line must be parallel with the airplane's line of flight. The vertical axis must

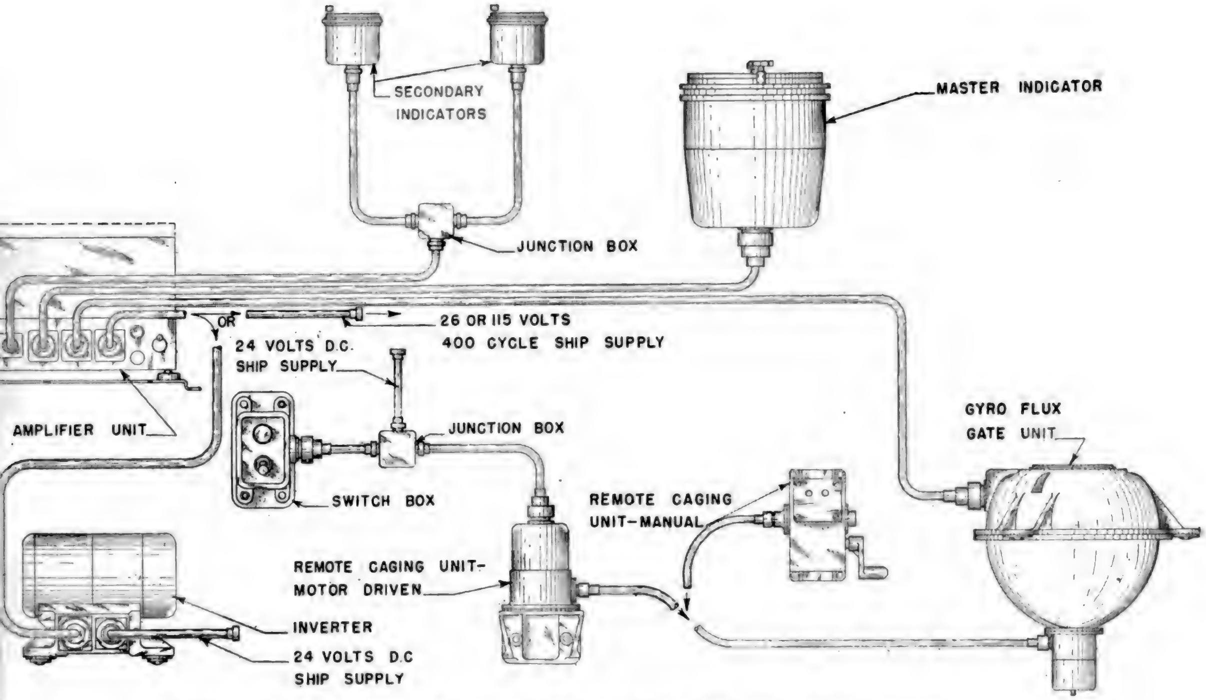


Figure 110. Schematic diagram—gyro-stabilized flux-gate compass system.

rallel to the vertical axis of the ship in normal

Amplifier. The amplifier should be installed se as possible to the master indicator, where be available to the navigator. Sufficient space be allowed for ventilation and for removing over when adjustments are needed. All conns must be installed with smooth bends. The must be grounded to the primary structure of rcraft. The controls, cable connections, etc., be on the front panel of the unit where they e available in flight.

Indicators. (1) The master indicator should unted where the navigator can see it at all and where he has ready access to the knob to adjust for magnetic variation. Space must owed for cable connections and for removal the panel.

When needed, as many as six repeater indi- may be installed at other stations. They are cted in parallel, with leads from a junction t the amplifier. Any remote, indicating indi- may be used as a repeater indicator.

Remote-control Unit for Caging Mech- . The control for the caging mechanism, figure ncludes a switch and a signal light (fig. 112) navigator's station, and a motor. Room must vided for removing the signal light and for ing motor brushes. It is important that the mechanism in the transmitter be synchronized

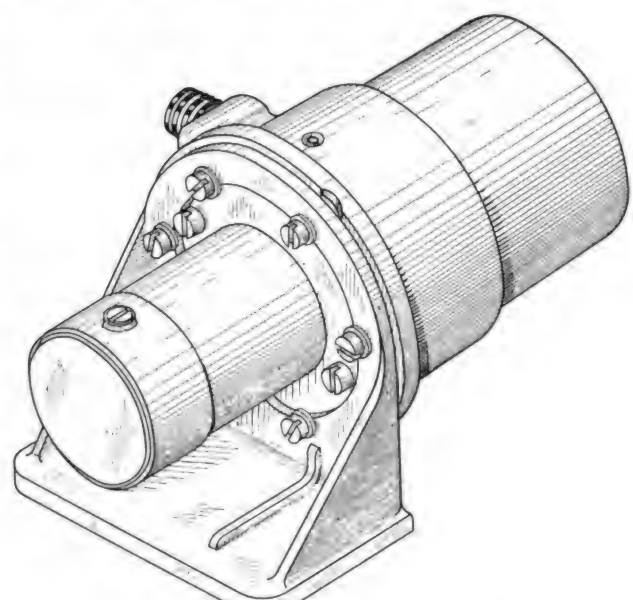


Figure 111. Remote electric caging unit—flux-gate compass.

with the caging motor during installation. In other words, the gyro must be uncaged when the red light on the control box is off.

f. Inverter. To avoid voltage drop, the inverter when used, should be installed as close as possible to the d-c source. Ventilating space must be provided.

g. Use of Installation Instructions. The foregoing installation instructions are general only. When any flux-gate compass units are to be installed,

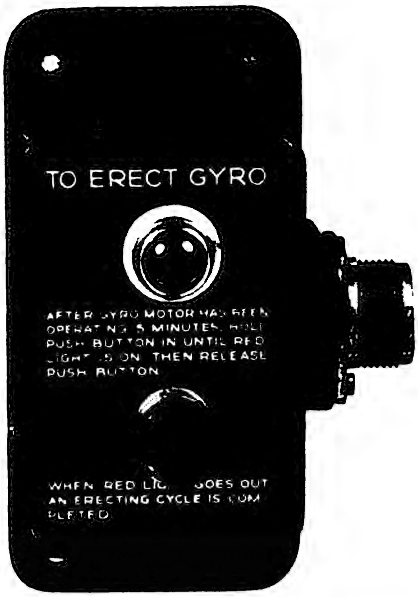


Figure 112. Switch-box, flux-gate compass.

: Technical Orders pertaining to this equipment 1 to the airplane on which installation is to be ,de should be consulted and carefully followed. mplete wiring diagrams and other instructions : given.

'. Compensation Procedure

a. General. The process of compensating a mpass system, that is, correcting as closely as ssible for errors caused by magnetic influences thin the airplane and plotting the final deviations various headings, is called "swinging the ship." ıder service conditions, this process must be re- ated frequently because the magnetic condition of : airplane changes constantly. The instructions ven in paragraph 38 should be followed.

Note. For the entire compensation procedure, the vari- on knob should be set on zero. ONLY the uncorrected d is read for the compass swing.

b. Compensating for Deviation in Flux-gate ompass. Compensation for magnetic deviation is rformed only at the master indicator. Since com- nsation mechanism is entirely mechanical, contain- g no magnets, correction can be made at any 15° ading without any effect at other stations. Each aster indicator has a cam-adjustment wrench which nsists of a knob at the top of the indicator dial d a special screw driver for adjusting the screws f the 24 compensation cams. When this knob is rned out, the bezel ring can be removed and the m screws become accessible. Turning the screws anges the contour of the cam and introduces a plus or minus spread between the readings of the pointer and the uncorrected dial by causing the pointer to lead or lag. There are three general methods of adjusting the compensating mechanism.

(1) *By manually turning master indicating mechanism.* A small knob is located on the back of later type master indicators. When this knob is pushed in, it engages a clutch on the induction motor and thereby drives the entire gear train. After dis- connecting the power from the master indicator, and removing the front cover as described in paragraph 44*b*, push in the knob and turn it until the pointer is exactly opposite one of the 15° headings where the deviation is 1° or less, for example, 120°. Adjust the compensating screw opposite the 120° mark until the difference between the uncorrected dial reading and the pointer reading is the deviation for 120°. Repeat this procedure on each successive 15° heading until the 24 screws have been adjusted. Check the compensation by turning the master indi- cator knob in the opposite direction and making any necessary adjustments.

(2) *By using test transmitter.* The test transmit- ter is particularly useful in compensating older type indicators which do not have the knob for manually turning the pointer. With power to the compass turned off, remove the AN plug of the amplifier and connect it to the tester. Connect the plug of the tester to the amplifier, and place the switch on the tester to the test position. Turn on power to the amplifier and rotate the knob on the tester to cause the uncorrected dial and pointer on the master indicator and the pointers of the repeater indicators to turn. Remove the front cover to expose the compensating screws. (See par. 44*b*.) Using the knob on the test transmitter, turn the uncorrected dial of the master indicator to the heading where minimum deviation was observed. The pointer should be within $\pm 2°$ of an exact 15° heading. Adjust the compensating screw next to the pointer until the correct magnetic heading is obtained. For example, if minimum deviation was found to be at a heading of 285° and an uncorrected dial reading of 284° was obtained for this heading, the knob on the tester should be turned until a reading of 284° is obtained on the uncorrected dial. The compensating screw next to the pointer should be adjusted until the pointer indicates the correct magnetic heading of 285°. This procedure is then repeated for each successive 15° heading. The knob on the tester is then turned in the opposite direction and any further adjustments on any 15° heading are made. The front cover is then replaced.

(3) *Turning airplane.* If the above method is not practical or desired, the airplane must be turned to the required headings, either by placing it on a turntable or by jockeying it on the ground. In this case, the power for the compass system is turned on and 5 minutes later the gyro is erected by going through the "cage—uncage" cycle. After the gyro has set itself vertical to the ground, the airplane is turned to the heading of minimum deviation. Compensating adjustments are made as in preceding paragraph 44 *b*.

(4) Correction for deviation can be performed while flying. An adjustment for one heading usually does not affect the pointer at another heading.

45. Inspection, Maintenance, and Lubrication

a. INSPECTION. (1) *Preflight.* With the gyro uncaged, apply the rated power to the compass system for 5 minutes. Run through the cage and uncage cycle. Observe the operation of the compass during taxying. If it does not respond to direction changes, check as directed in Technical Orders.

(2) *50-hour.* Check the readings as on the preflight. Check the security of all units. Adjust the inverter.

(3) *100-hour.* Check the deviation at North, East, South, and West. The pointer of the master indicator and each repeater indicator must be within 2° of correct at all stations. If not, check the applied voltage, which must be within 10 percent of that specified. If the voltage is correct, recompensate. If this does not correct the error, check for troubles within the system.

(4) *500-hour.* Remove the transmitter and indicators for a check at an authorized overhaul base.

b. MAINTENANCE. (1) Clean all parts of electrical equipment. Tighten or resolder any loose connections. Check the motor and inverter brushes for free movement in the holders and for wear. Replace them if badly worn. Be sure replaced brushes seat properly. Check the tension of brush springs.

(2) The mechanic should study the Technical Orders pertaining to this equipment to determine the common service troubles, probable causes, and remedies. No attempt is made here to give detailed instructions.

c. LUBRICATION. No lubrication is required except at depot overhaul.

d. STORAGE. The flux-gate transmitter should not be stored near open wiring, or in places where it will be subject to excessive cold or heat.

e. HANDLING. The gyro-stabilized flux-gate compass system is a precision instrument which must be handled with great care and only by authorized persons. When transported, the transmitter must remain upright with the gyro caged. None of the units are constructed to undergo rough treatment. Personnel working near installed compasses should be warned of the damage which may result from carelessness.

SECTION X
AIRCRAFT FLIGHT INSTRUMENTS

46. General

The equipment generally classified as "aircraft flight instruments" consists of the airspeed tube, the rate-of-climb indicator, the airspeed indicator, the altimeter and gyro instruments covered in section XI. These devices provide the pilot with indications of the airplane's altitude, speed through the air, rate-of-climb or descent, rate-of-turn, and the height above sea level or the ground. All of these indications are essential for safe and efficient flight.

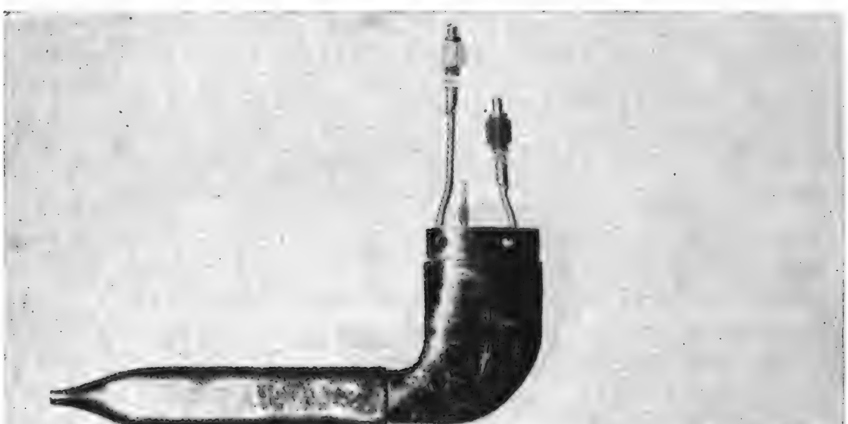
47. Airspeed Tube

a. GENERAL. (1) The airspeed tube is used for applying impact ("pitot") pressure and static (still) pressure to certain instruments. Impact pressure is the reaction of the atmosphere to the movement of the airplane. Static pressure is the pressure of undisturbed air around the airplane, that is, the pressure that would be exerted on the airplane if it were not in motion.

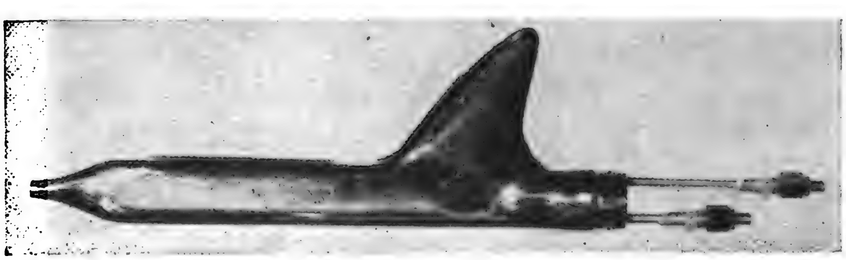
(2) From the airspeed tube, the impact and static pressures are conveyed separately to the airspeed indicator, which indicates the speed of the airplane as it moves through the air. The indication is produced by the difference between pitot and static pressures. Static pressure alone is conveyed from the airspeed tube to the altimeter, which indicates altitude above sea level by comparing static pressure with sea-level pressure. Static pressure is conveyed also to the rate-of-climb indicator, which computes the rate of ascent or descent of the airplane by measuring the corresponding rate of decrease or increase of static pressure.

(3) A type of airspeed tube now available provides only impact pressure. Static pressure is obtained from a suitable position outside the fuselage. A mast from some structural part of the airplane is not needed for this installation.

b. DESCRIPTION. (1) The airspeed tube is a single unit with no detachable parts. Its axis is placed in the aircraft's direction of flight. The front of the tube is open so that it can receive the full impact of the atmosphere during flight. This impact pressure is transmitted by airtight tubing to the air-



① *Mounted under nose of fuselage.*



② *Mounted forward of leading edge of wing.*

Figure 113. Airspeed tubes—streamlined types.

indicator. Small holes admit static pressure separate chamber in the tube. This pressure ısmitted by airtight tubing to the airspeed indi- the rate-of-climb indicator, and the altimeter.

The two general types of airspeed tubes are ated in figure 113. One type (fig. 113① is ıed for installation on a tapered streamline xtending below and forward of the fuselage's The other type, figure 113②, is installed on n extending forward from the leading edge of ing. The two varieties of tube are funda- lly similar in construction and operation. (See 4.) Both are made of heavy-gauge brass seam- ıbing and have two sections or chambers, the (impact) pressure section and the static- ıre section.

fin to prevent moisture from entering the pitot-tube riser. The riser, located in the fin, receives the static pressure and transmits it through airtight tubing to the airspeed indicator, rate-of-climb indicator, and altimeter.

(5) Most airspeed tubes are provided with two heating elements to prevent icing during flight. (See fig. 114.) The operation of these elements is controlled by a switch in the cockpit. The elements are practically indestructible and will usually give good service for the life of the tube. Some tube heating systems are designed for operation on 110-volt alternating current, and others for 12- or 24-volt direct current.

(6) In one type of tube, porcelain beads are used as insulation for the internal wiring, and will

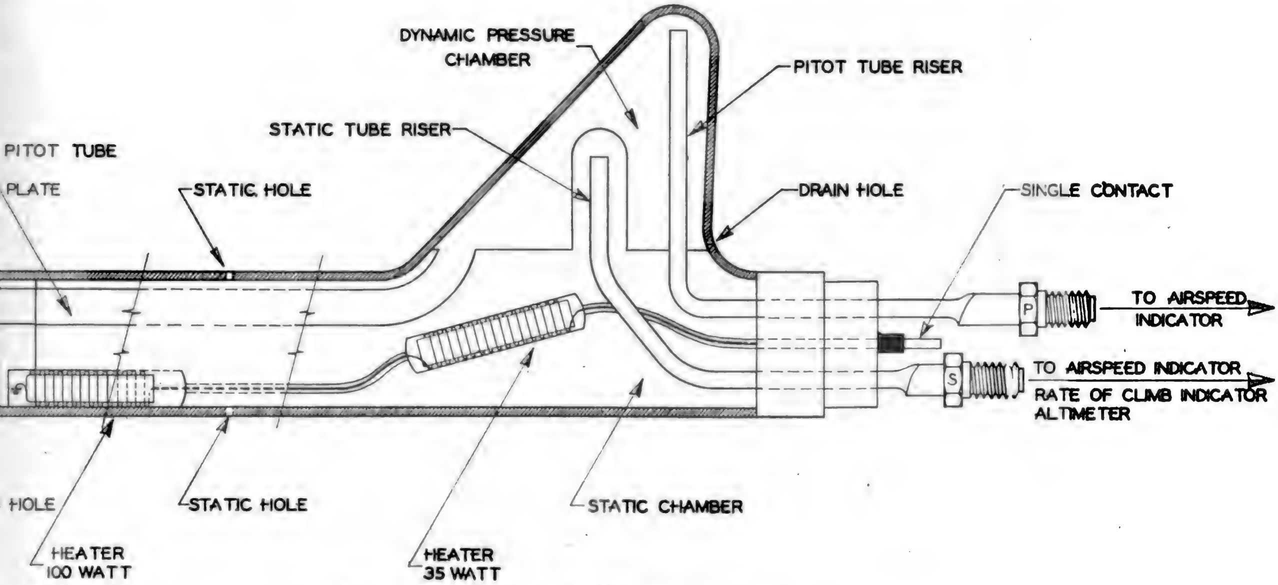


Figure 114. Airspeed tube—cross section.

The pitot-pressure section, open in front to e the full impact of the atmosphere, has a plate to prevent blow-back of moisture and ıto the tube. One small drain hole, below the plate, disposes of moisture and condensate. A in the fin receives the impact pressure and nits it through airtight tubing to the airspeed tor. Use of the riser makes less likely the ıce of dirt and moisture into the tubing leading indicator.

The static-pressure chamber is vented to mosphere through three small holes on top of ıbe and three on the bottom. The opposite ɔn of the holes provides a compensating effect insures a more accurate registering of static ıre. These static holes function also as drain another drain hole is often provided in the

produce a slight rattling noise if the tube is shaken. This noise is not necessarily an indication that the tube is defective.

c. Operation. (1) Ordinarily the airspeed tube requires no attention from the pilot. Pitot and static pressures are transmitted automatically and instantaneously to the instruments.

(2) The electrical circuit of the heating elements in the airspeed tube is connected through the ignition switch for all engines in such a way that when the ignition switch is off, the electrical circuit of the tube is open, and when the ignition switch is on, the electrical circuit of the tube can be controlled by the "On-Off" switch labeled "Airspeed Tube." When icing conditions are encountered, the "Airspeed Tube" switch is turned on, and when icing is no longer likely, it is turned off.

3) To avoid unnecessary battery discharge, and prevent shortening of the life of the heating elenits, the switch should be off at all times when ting of the tube is not required.

. INSTALLATION. (1) Airspeed tubes are deied for different types of airplanes and for difent electrical systems. Technical Orders must be sulted for specific installation information.

2) The airspeed tube is mounted in a location ere there is minimum disturbance of the air due he motion of the airplane. Proper location varies ording to the type of tube and the type of airne on which it is installed.

3) The connections for the tubing between the peed tube and the airspeed indicator case are rked *P* (pitot pressure) and *S* (static pressure). ese connections must be made correctly and must airtight.

4) To permit removal and replacement of the e, a union is placed in each connecting line at point of attachment of the mounting boom or st to the wing or fuselage. The union is accessible ough an inspection door. To remove a tube, connect the unions, then remove the mounting ews and lock washers. The tube may then be led out of its mount a few inches, and the pitot l static tubing and the "snap-on" electrical contor disconnected. To replace the tube, this cedure is reversed. Detailed instructions for unting the tubes, for wiring, and for marking the ssure tubing, are provided in Technical Orders.

5) After installation of electrically heated tubes, electrical circuit is tested at the airspeed tube to ermine whether the connections are correct. Table hows the minimum voltage required at the tube h various power sources.

ble I. Minimum required voltages at airspeed tube with various power sources.

mbined generator d battery voltage	Battery voltage	Voltage measured at airspeed tube
14.25 volts	....	12 volts
28.50 volts	....	24 volts
....	12 volts	10.5 volts
....	24 volts	21 volts

(6) Most airplanes have a static pressure selec- valve mounted adjacent to the altimeter on the trument panel, if possible. This has an "alternate rce" port which may be used in flight as an ergency source of static pressure for the altiter, rate-of-climb indicator, and airspeed inditor if some failure of the normal static pressure encountered. This alternate source may give roneous indications.

e. INSPECTION AND MAINTENANCE. (1) The airspeed tube must be kept clean and free from moisture at all times. When the airplane is not flying, the tube (including all holes) must be covered with an appropriate sack made of cloth, canvas, or leather, with a streamer attached.

(2) If the heating elements do not function satisfactorily, the voltage test described in *d*(5) should be made.

(3) To prevent errors in airspeed indicator, altimeter, and rate-of-climb indicator readings, the airspeed tube and connecting tube must be leakproof. To test for leaks in the static-pressure system, connect the static holes to a source of suction and set the altimeter pointer to zero. Apply suction until the altimeter reads 1,000 feet altitude (about 1.05 inches Hg or 14.24 inches water), and then pinch off the suction. Maintain the suction for a period of 1 minute, meanwhile tapping the altimeter or instrument board to reduce friction in the pointer movement. The altimeter reading should not decrease more than 150 feet. A greater change indicates leakage in the system.

Caution: Do not apply pressure to static lines. Regulate slow application and removal of suction by noting the reading of the rate-of-climb indicator, which should not be permitted to exceed 2,000 feet per minute while making this test.

(4) To test the pitot lines, first seal the drain holes. With the airspeed indicator properly connected, connect the pitot opening of the tube to a source of pressure. Apply pressure slowly until the indicator reads 150 mph (about 0.82 inch Hg or 11.18 inches water); then pinch off the pressure. With the pressure maintained for 1 minute, the indicator reading should not drop more than 10 mph. The indicator or instrument board should be tapped during this period to reduce the friction of the pointer movement.

Caution: Do not apply suction to pitot lines.

48. Rate-of-Climb Indicator

a. GENERAL. The rate-of-climb (or "dive-and-climb") indicator shows the rate of gain or loss of altitude regardless of the attitude of the aircraft. The rate is shown in graduations of 100 or 200 feet per minute. The instrument is useful to the

not only in showing gains or

their rates, but also in s

turns are being made wi

in making it easier

descent in the app

not less than 2 inches to absorb

permit flexibility between the indicator

The tubing should be annealed after

These connections must be tight as a leak

the slightest amount at this point will cause

scale errors in the instruments.

(3) After installation, the leak test described in *f* below is performed to make certain that there are no leaks that might cause unsatisfactory operation of the instrument.

f. INSPECTION AND MAINTENANCE. (1) The general instructions regarding instrument maintenance in section XVI apply to the rate-of-climb indicator.

(2) At periodic intervals, the static system and the indicator case must be checked for leaks. This is done by setting the pointer to zero with the adjuster, breaking the static connection as close to the indicator as possible, and attaching a 2- or 3-foot length of ¼-inch rubber tubing. Apply a suction that will cause the indicator to read 2,000 feet per minute ascent, then pinch the hose as close to the indicator as possible and watch the pointer; it should return to zero immediately and stop there. If it continues to rotate past zero in the counterclockwise direction, there is evidence of a leak in the instrument case and the instrument must be removed and replaced.

49. Airspeed Indicator

a. GENERAL. The airspeed indicator shows the airplane's rate of speed through the air. Except in still air at normal sea-level atmospheric pressure, the indicated airspeed is different from ground speed. However, the pilot can calculate ground speed from the indicated airspeed if he knows the altitude at which he is flying, the temperature, and the direction and speed of the wind. Thus the airspeed indicator is useful in the following:

(1) Estimating actual ground speed. An accurate estimate is necessary when the time required to reach a landing field or tactical objective must be determined.

(2) Determining the best throttle setting for the most efficient flying speed.

(3) Determining the best climbing and gliding angles.

(4) Determining whether diving speed is safe for the airplane structure.

(5) Indicating when the airplane has attained flying speed at take-off, and when stalling speed is being approached during maneuvers or landings.

b. PRINCIPLE OF OPERATION. The airspeed indicator operates on the principle of differential pressure. Impact pressure from the airspeed tube is conveyed into a diaphragm in the airtight instrument case. Static pressure is conveyed from the airspeed tube into the instrument case so that it surrounds the diaphragm. When the airplane is motionless in still air, it has no airspeed. The impact pressure equ static pressure, and the diaphragm is in equilibriu When the airplane is in flight, impact pressure greater than static pressure. This difference i creases as the airplane's speed increases, and thus corresponding distortion of the diaphragm—due the greater (impact) pressure inside—occurs. T distortion of the diaphragm, being a measure of t differential pressure, is thus also a measure of t airspeed. The amount of distortion can be registe by an indicating mechanism in terms of miles p hour.

c. DESCRIPTION. The internal mechanism a operating principles of all airspeed indicators a similar. There are only minor differences in co struction. Low- and high-speed types are shown figures 117① and ②.

(1) The cross section of an airspeed indica is shown in figure 117③. The mechanism consi essentially of an airtight diaphragm assembly i which impact pressure is led, and a mechanism f multiplying its deflection. This mechanism is co posed of a rocking shaft assembly with two levers sector assembly with a sector lever, a hand or poin staff, and a pinion. A hairspring secured to the ha staff and anchored to the mechanism body eli inates backlash in the mechanism and holds t diaphragm lever against the diaphragm bridge. T housing for the instrument is an airtight case. O connection (marked *S*) in the back of the c admits static pressure to the interior of the ca the other connection (marked *P*) admits impact, pitot pressure to a tube leading into the diaphrag Each connection is made up of an internal p thread insert in the case and a nipple union.

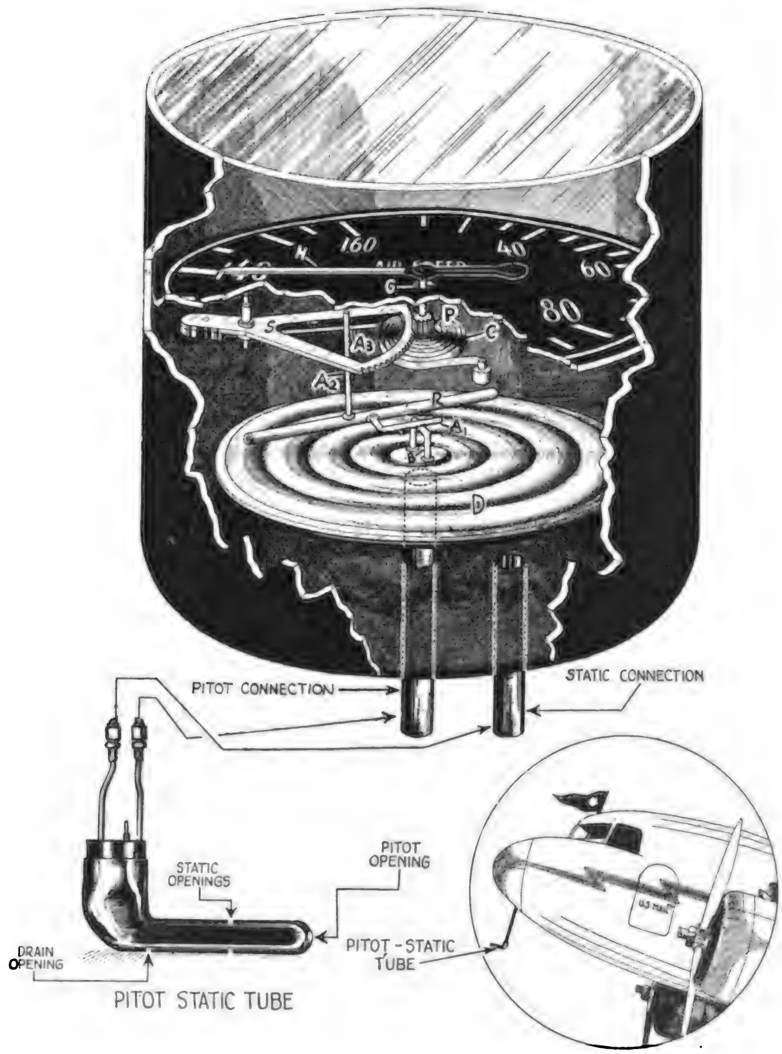
(2) In external appearance various models a similar, except for the varying lengths of the ca and the dial markings. The cover glasses of so types are held in place by snap rings. Other ty have two-piece cases, held together with screws, insure an airtight seal.

(3) The dials of various models are gradua at intervals of 1 or 5 mph through ranges depe ing on the needs of different airplanes. For a sl airplane, the range may be from 15 to 100 m For the fastest airplane, the range is up to 700 m In some models, the pointers may move more th one revolution, and the dials accordingly ha secondary graduations.

(4) The graduations of some airspeed indicat are of luminous paint. In other models the gradu tions are made of a material which glows w fluorescent light.

① *Low-range type.*

② *High-range type.*



③ *Showing mechanism and connection to pitot-static tubes.*

Figure 117. Airspeed indicators and connections.

d. OPERATION. (1) The operation of the instrument is automatic and requires no adjustments by the pilot.

(2) Since there is always some atmospheric disturbance about the pitot-static tube, the differential pressure does not indicate the exact airspeed. To compensate for this discrepancy (called "installation error"), the pilot refers to a correction card. This card is prepared by flying the airplane over a measured speed course and noting the errors in the airspeed indication.

(3) Errors may result also from imperfect calibration of the instrument (with respect to the standard airspeed-pressure relationship) and from the effects of temperature changes in the instrument. For a change in instrument temperature of 45° C. (113° F.) to —35° C. (—31° F.) the error should not, however, exceed 3½ mph at any point on the scale.

(4) Standard competing devices can be used to compute the true airspeed from the indicated speed in certain cases. The instructions given in Technical Orders should be consulted.

e. INSTALLATION. (1) The airspeed indicator is grouped with the other flight instruments. It is mounted so that the zero on the dial is on the top side. Installation is made in accordance with various airplane and instrument board drawings. Mounting screws, as required, are furnished with each instrument.

(2) The *P* (pitot) and *S* (static) connections on the back of the instrument case are connected to the corresponding connections on the airspeed tube by means of airtight lines of seamless copper or aluminum tubing. When seamless copper tubing is used, the fittings will be either three-piece solderless or cone unions. When seamless aluminum-alloy tubing is used, the fittings should be aluminum alloy 17ST, anodically treated, solderless fittings. The connecting lines are carried inside the fuselage and wing structure to prevent damage. The altimeter and rate-of-climb indicator are also connected into the static line. Each pitot and static-pressure line should incorporate a flexible connection located behind the instrument board in such a manner as to complete the installation of the instrument board from the vibrations of the airplane structure.

(3) In the calibration of airspeed-indicator installations on various types of airplanes, it has been found in some cases that the maximum permissible diving speeds exceed the scale range of the instrument. Whenever this condition exists, the airspeed indicator is replaced with one having the necessary higher scale range.

f. INSPECTION AND MAINTENANCE. The general points on service inspection and maintenance of instruments, given in section XVI, are applicable to airspeed indicators.

50. Altimeter

a. GENERAL. Altimeters are used in aircraft to measure altitude above sea level, and altitude above some field of reference on the ground. Measurement of altitude above sea level is made by the "altimeter-setting" system. Measurement of altitude above the ground is done by the "field elevation" system. These systems are explained in *d* below.

(1) The specific uses of the altimeter-setting system are to—

(*a*) Indicate at all times the elevation of the airplane above sea level so that it can be compared with strip maps for the purpose of clearing critical points and mountain peaks safely.

(*b*) Use advantageously the meteorological data supplied by weather stations, such as wind velocities and directions for various elevations, and elevations of cloud and storm formations that are to be avoided in flight.

(*c*) Observe and correctly follow airways traffic regulations.

(2) The specific uses of the field-elevation system are to—

(*a*) Determine accurately the vertical distance between the aircraft and objectives on the ground when performing tactical missions.

(*b*) Indicate the elevation of the airplane above the runway for coordination with other instrument indications when making instrument landings.

b. PRINCIPLE OF OPERATION. All altimeters (except radio altimeters) used by the Army Air Forces operate by means of an evacuated, sealed aneroid. Since atmospheric pressure decreases with increasing altitude according to a fairly definite relationship, the altitude of an airplane will be indicated by the surrounding atmospheric pressure. The atmospheric pressure is measured by means of an evacuated aneroid which expands or contracts according to atmospheric pressure changes. Thus the altimeter is essentially a barometer designed to show atmospheric pressure in terms of altitude.

c. DESCRIPTION. (1) All altimeters used by the Army Air Forces operate on the basic principle shown schematically in figure 118. The evacuated aneroid mechanism is very sensitive and well bal-

anced, jeweled bearings being used on all pivots to reduce friction. Static pressure from the airspeed tube is admitted to the airtight instrument case. Since the static pressure decreases with altitude, A few are calibrated up to 50,000 feet. Multiple-pointer systems make it possible to read the instruments accurately to at least one-half the smallest unit graduated on the scale.

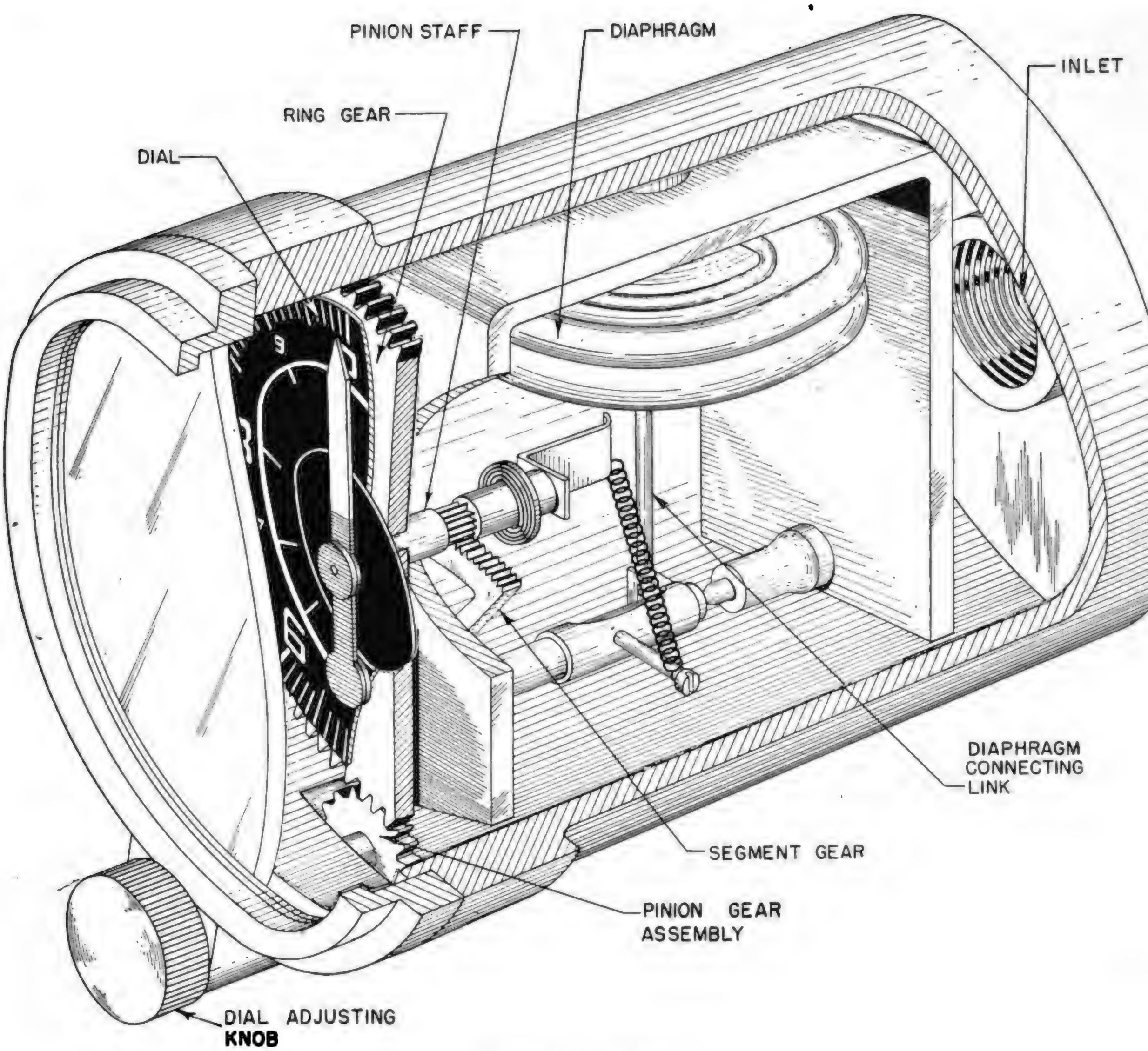


Figure 118. Altimeter.

exerting less pressure on the aneroid, the aneroid tends to expand with increasing altitude. The amount of expansion is controlled by a rod or other device serving as a temperature compensator, which is necessary because of the pronounced effect of changing temperatures on air pressure. The movement of the aneroid is transmitted through a rocker shaft and sector to a pinion-and-gear assembly, which causes the pointers to move on the graduated dial.

(2) Standard models of altimeters for tactical operation have calibrated ranges of from 0 feet (sea level) or —1,000 feet below sea level to 35,000 feet.

(3) Some altimeters have single altitude scales, single barometric-pressure scales with index markers, two reference markers, and three pointers, as in figure 119. The altitude scale, with major divisions of 0 to 10, is fixed. The pointers, reference markers, and barometric scale rotate and indicate with reference to the altitude scale, as described under *b* below. Setting knob at the bottom front of the instrument case drives two pinions in opposite directions. One pinion rotates the barometric scale and reference markers, which are known as the "zero setting system"; the other pinion rotates the

aneroid mechanism assembly, of which the pointers are a part. A long pointer, an intermediate pointer, and a short pointer are concentrically arranged and indicate on the one common dial. A long pointer makes one revolution for a change of 1,000 feet, and an intermediate pointer makes one revolution for 10,000 feet. A short pointer would, if not restrained, make one revolution for 100,000 feet. To cover the full range of the instrument, a long pointer makes 36, an intermediate pointer 3.6, and a short pointer 0.36 revolutions.

Figure 119. Altimeter—sensitive.

(4) In these altimeters the positions of reference markers are read on the same dial as the pointers. The outer marker, rotating on the edge of the dial, makes one revolution for 1,000 feet, and the inner marker one revolution for 10,000 feet. The barometric scale, a sector of which is visible through an opening in the instrument dial, has a standard range of 28.1 to 31.0 inches Hg, with unit graduations of 0.02 inch Hg. When the range limit is reached at either extreme, a shutter blanks out the visible sector of the barometric scale, and the barometric pressure must then be calculated from the positions of the reference markers.

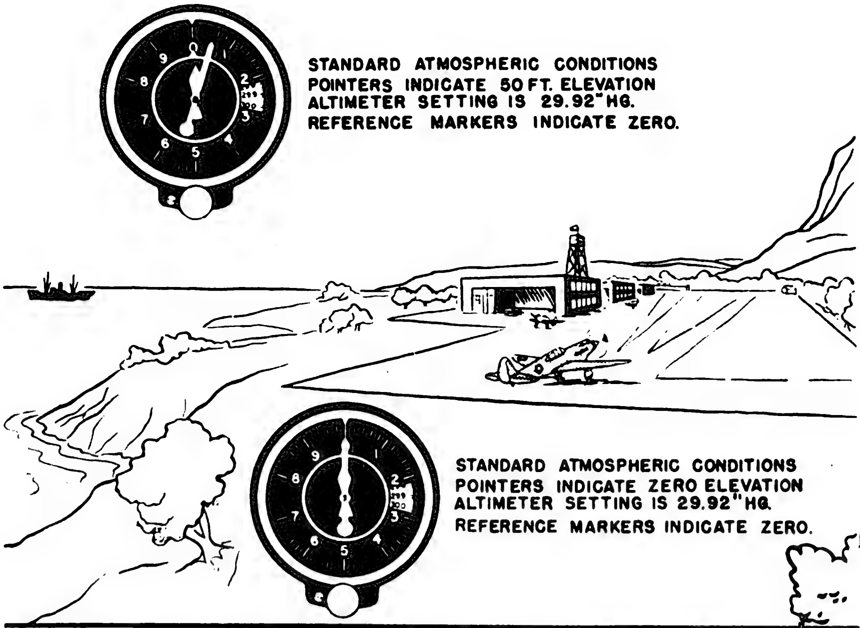
(5) In one recent model the reference markers and the barometric scale with its index marker are omitted. For a zero-setting system a barometric-pressure counter, operated by a knob, is used instead of the barometric scale. The pilot can see, through an opening in the lower part of the dial, the values turned up by the counter mechanism. The range of the counter is 28 to 30.99 inches Hg.

(6) The typical altimeter is inclosed in a two-piece bakelite or aluminum case which is provided with a vent in the rear case wall for connection to the static line of the pitot-static system. Since this instrument must be sealed airtight, its only opening is through the static vent. Some older altimeters are provided with 3-volt ring lights and reflectors, the receptacles being molded integral with the instrumer case. Later type sensitive altimeters eliminate th 3-volt ring lights and instead are designed fo fluorescent lighting.

d. Operation. The atmospheric pressure at given altitude in any locality varies with changin weather conditions. Furthermore, the pressure at given altitude in one locality may differ from th pressure existing at the same moment at the sam altitude in another locality. It is therefore necessa to adjust an altimeter frequently, according to th changing altitude-pressure relationship, so that i altitude indications will be accurate. Adjustmen are made by means of the adjusting knob. By turn ing the knob the pilot can change the position of th aneroid with respect to the pointers.

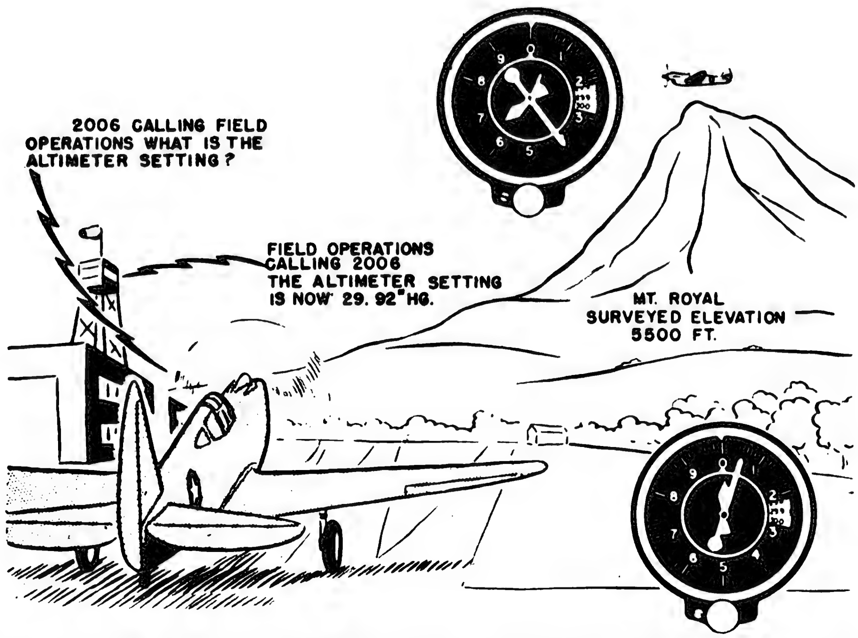
(1) If a cross-country flight is to be made, ju before the take-off the adjusting knob is turned un the pointers indicate the altitude of the station abo sea level plus the height of the altimeter above th ground. The barometric reading of the instrume will then be the barometric pressure at sea level (n at the station, unless it is at sea level). After tak off the altimeter pointers will show the altitude the airplane above sea level so long as the origin altitude-pressure relationship remains unchanged. soon as this relationship changes, the altitude inc cations of the instrument will become unreliab unless the instrument is properly adjusted. T pilot, however, is kept informed of the changi altitude-pressure relationship through radio repo from stations along his route. Each station repo to the pilot the prevailing atmospheric pressure sea level (computed by the station from station al tude and local barometric pressure.) The pilot tur the altimeter adjusting knob as often as necessa to keep the instrument's barometric-pressure readi the same as barometric pressure at sea level. So lo as this is done, the altitude of the airplane above level will be indicated correctly by the pointe When this system is used, the pilot can calculate elevation above the ground by determining from topographic map the elevation above sea level the land over which he is flying and subtracting t elevation from his altimeter reading (elevation the airplane above sea level).

(2) The function of the triangular referer markers, provided only in altimeters with the ba metric scale and index (not the barometric-press counter), is to facilitate the adjustment of the a meter. The reference markers move when the justing knob is turned. Since they move on the la dial, the altimeter can be more finely adjusted w



WHEN USING THE "ALTIMETER SETTING" SYSTEM THE POINTER WILL ALWAYS INDICATE THE ALTITUDE IN FEET ABOVE SEA LEVEL UNDER STANDARD ATMOSPHERIC CONDITIONS.

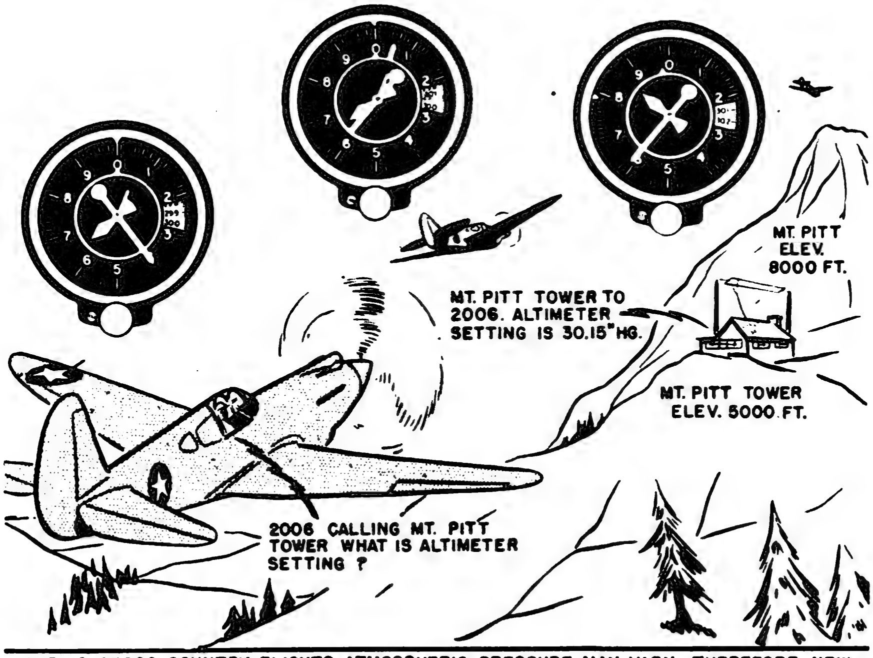
①



PRIOR TO TAKE-OFF THE POINTERS ARE SET TO SURVEYED FIELD ELEVATION THE POINTERS WILL THEN ALWAYS INDICATE HEIGHT ABOVE SEA LEVEL THUS ALLOWING PILOT TO CLEAR MOUNTAIN PEAKS OR OTHER CRITICAL POINTS.

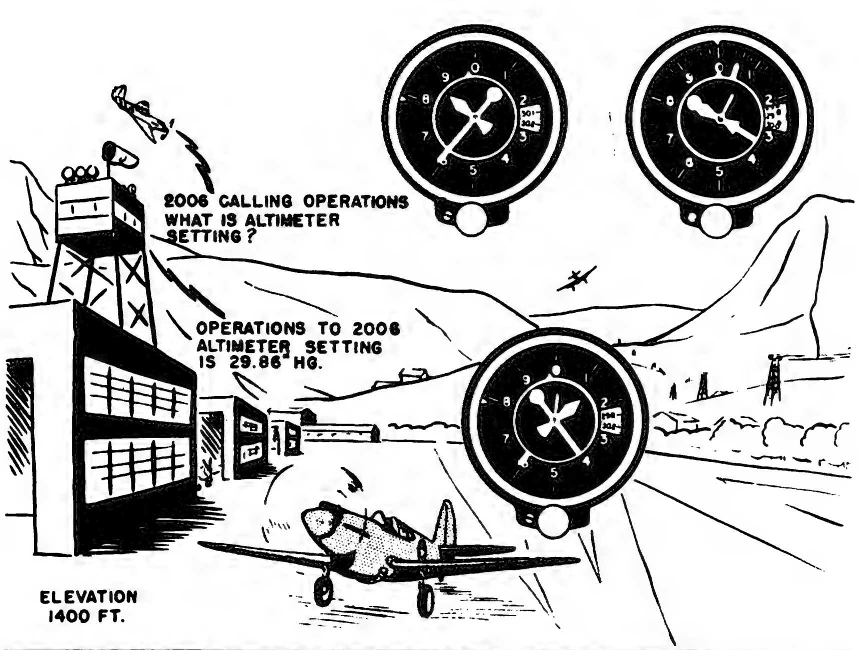
②

Figure 120. Use of the altimeter.



DURING CROSS COUNTRY FLIGHTS ATMOSPHERIC PRESSURE MAY VARY. THEREFORE NEW "ALTIMETER SETTING" READINGS ARE OBTAINED DURING FLIGHT TO ALLOW PILOT TO CONTINUE CLEARING MOUNTAIN PEAKS OR OTHER CRITICAL POINTS.

③



PRIOR TO LANDING "ALTIMETER SETTING" IS AGAIN OBTAINED FROM FIELD & RESET IF NECESSARY. THE POINTERS WILL THEN INDICATE THE SURVEYED ELEVATION OF THE FIELD WHEN THE PLANE LANDS ON RUNWAY.

④

Figure 120—Continued.

reference to the markers than with reference to the barometric-pressure scale. During flight, therefore, the pilot may receive (by radio) corrections in terms of reference marker positions as well as barometric-pressure readings. By moving the reference markers to the reported correct positions, he will be moving barometric-pressure scale to the reported correct position—a position probably more accurate than it would have been if the adjusting knob has been turned with reference to the scale. Thus, with the accurate barometric-pressure reading, the pilot will have more reliable altitude readings. With altimeters equipped with barometric-pressure counters, reference markers are not needed, because the correct counter reading can be obtained easily by turning the knob with reference to the counter.

(3) Figure 120 illustrates the use of an altimeter equipped with the barometric scale and reference markers.

(4) The following terms, defined briefly, are used in connection with altimeters.

(*a*) *U. S. Standard Atmosphere.* Atmosphere of which the pressure and temperature at sea level are, respectively 29.92 inches Hg and 15° C.

(*b*) *Altimeter setting.* Approximate barometric pressure at sea level as computed from the pressure at any given station.

(*c*) *Field-elevation pressure.* Barometric pressure at the field.

(*d*) *Pressure altitude.* That altitude in the U. S. Standard Atmosphere which corresponds to a given pressure.

(*e*) *Station pressure.* Barometric pressure at the weather station.

(*f*) *Pressure-altitude variation.* The difference in feet between the indicator of a perfectly calibrated altimeter and the true, or actual elevation.

(*g*) *Height setting.* Reading in feet of the station altimeter pointers when the instrument is set at sea-level barometric pressure.

(*h*) *Altimeter scale error.* The difference in feet (expressed algebraically) between the altimeter reading and that altitude in the U.S. Standard Atmosphere which corresponds to the atmospheric pressure to which the altitude is exposed.

(*i*) *Altimeter scale correction.* The amount in feet that must be added to, or subtracted from, the altimeter reading to obtain the altitude in the U. S. Standard Atmosphere that corresponds to the pressure to which the altimeter is exposed.

e. Installation. (1) Installation instructions given in section XV apply generally to altimeters. The altimeter is connected to the static line of the pitot-static system. If the pitot-static tube is correctly placed and aligned in the direction of flight, and if there are no leaks in the system the altimeter will operate correctly.

(2) After installation, the leak test described in *f*(5) below, must be made to insure that there are no leaks in the pitot-static system or in the altimeter.

f. Inspection and Maintenance. The general instructions in section XVI regarding inspection and maintenance apply to altimeters. The following also apply:

(1) Just before take-off, set the altimeter for use according to either the field-elevation pressure or the altimeter-setting system. For local flights or practice in instrument landings, turn the knob so that the pointers indicate 0. With this setting the barometric-scale or counter reading will be the pressure to which the instrument is exposed. For cross-country flights, turn the knob so that the pointers indicate the surveyed elevation of the field plus the height of the instrument above the ground. With this setting, the barometric-scale or counter reading will be sea level barometric pressure.

(2) Before flight, check the knob for free turning. Pointers, reference markers if used, and the barometric scale or counter should operate when the knob is turned.

(3) If the altimeter has reference markers, check the zero setting system on the ground as follows: Set the pointers of the airplane altimeter at 0, vibrating the panel two or three times while doing so. The reading of the reference markers should now be ±30 feet of the pressure altitude on a portable altimeter used for comparison. The portable altimeter has previously been compared with the station altimeter and corrected if the scale reading has been found inaccurate. (Likewise the barometric-scale reading should be the same as the barometric reading of the portable altimeter.) If the error exceeds ±30 feet, loosen the small screw just to the left of the setting knob. (Do *not* attempt to pull the screw out.) When the screw is loose, push it to the left as far as it will go. Then pull the setting knob outward and turn it so that the reference markers correspond to the pressure altitude obtained from the portable altimeter. Push the knob in, and reseat the lock and screw.

(4) If the altimeter has only a barometric-pressure counter, the zero-setting system is checked on the ground in a different manner. Turn the adjusting knob until the counter reads 29.92 inches Hg (sea-level pressure of U. S. Standard Atmosphere), lightly tapping the instrument meanwhile.

altitude reading at this setting should be within feet of the altitude corresponding to the read- aken from a standard mercurial barometer. If rror exceeds ±30 feet, tighten all connections. e error exceeds ±50 feet, the instrument must moved, marked for repair, and sent to an over- depot. It should be accompanied by a descrip- of the defect. If the altimeter's error is between and ±50 feet, see that the counter reads 29.92 then remove the soft wax in the screw hole at eft of the adjusting knob. Loosen this reset v at least four turns. By turning the knob, set pointers at the altitude corresponding to the ng obtained from the standard mercurial barometer. Tighten the reset screw to engage the counter, and refill the hole with soft wax.

(5) An altimeter cannot operate accurately unless the airspeed tube is properly placed and the pitot-static system and altimeter case are absolutely leakproof. To check the case for leaks, disconnect the instrument at the static connection. Place a short piece of rubber tubing over the vent marked *S*. Apply pressure until the altitude indication decreases 500 feet. Now pinch off the tubing and watch the pointer. In 10 seconds the pointer position should not change more than 20 feet. If it changes more than this, the instrument case leaks and must be replaced.

SECTION XI
GYROSCOPIC INSTRUMENTS

General

PURPOSE AND USE. The use of instruments ch operate on the gyroscopic principle is essential nodern airplanes. When a pilot cannot see some d object outside his airplane, such as the earth loud outlines, he cannot with his unaided senses rmine accurately the attitude of the airplane. thermore, as long as it is not certain that the lane is in straight and level flight, the readings of magnetic compass are unreliable, because any from the vertical would cause compass deviation. oscopes, by means of which dependable artificial rences can be maintained, are therefore incorted in certain aircraft instruments. By means hese instruments, the attitude of the airplane be determined at any time, and the use of the netic compass can be governed accordingly.

INSTRUMENTS COMMONLY USED. Three types yroscopic instruments are commonly used on irplanes:

1) The bank-and-turn indicator shows the corness of the banking angle and the banking angle elated to rate of turn of the airplane. Thus the can more easily control the flight of the aire under conditions of poor visibility, or when desirable to eliminate any yawing or turning on.

2) The directional gyro indicates the amount irn and gives the exact heading in both straight t and turns. It supplements the compass, pros a fixed reference within the cockpit upon which pilot can rely, and permits him to steer the aire accurately when visibility is poor.

3) The gyro horizon shows the banking, climband descending motions of the airplane. The ature airplane and the gyro-controlled horizon on the indicator show the pilot the attitude of airplane with respect to the earth's horizon.

GYROSCOPIC PRINCIPLES. The gyroscope is tially a wheel which may be suspended so that n spin freely about a given axis. If no external e is applied, the wheel will tend to remain spin about the axis without tilting as long as the d of rotation is at or above a certain minimum. gyro may be mounted in either of two ways rcraft instruments:

) It can be mounted in gimbal rings in such y that while spinning it will remain rigid—s, will not change its plane of rotation in space —during any movement of the airplane around the three directional axes. In effect, the airplane will move about the gyroscope. This kind of mounting, illustrated in figure 121, is used for the directional gyro and the gyro horizon.

(2) The gyroscope may, on the other hand, be mounted so that it will precess when the airplane moves about the vertical axis; that is, when the airplane changes its course. When a force, which tends to rotate a gyroscope about an axis at right angles to its axis of rotation, is applied, the gyroscope will turn about a third axis which is perpendicular to both of those mentioned. This movement, which is at right angles to the direction of the applied force, is called precession. A mounting which permits precession, illustrated in figure 122, is used in the bank-and-turn indicator.

d. Some gyroscopes are electrically driven. In some types the gyro rotor is attached to the same shaft as the armature; in others, the armature itself acts as the gyro rotor. Other gyroscopes are air-driven as described in paragraph 52.

52. Vacuum System

a. GENERAL. Many gyroscopic flight instruments contain small air-driven gyros mounted in airtight cases. A venturi tube, shown in figure 123, or an engine-driven vacuum pump causes the rotor of the gyroscope to turn at approximately 12,000 rpm. The rotor will not change its plane of rotation unless an external force is applied as described in paragraph 51*c*(2).

b. VENTURI TUBE. (1) If a tube is connected from a gyroscope case to the throat of a venturi, air from the case will flow into the venturi. This produces a partial vacuum in the gyroscope case. If an inlet from the atmosphere (fig. 124) is directed toward the buckets of the gyroscope wheel, the jet of air rushing to fill the partial vacuum will spin the wheel at high velocity.

(2) If no vacuum pump is used, venturi tubes are employed as the source of vacuum. However, since a venturi develops insufficient suction during glides, since it may freeze and become inoperative, and since a venturi installation may alter the airflow characteristics of the airplane, vacuum pumps are installed on all tactical airplanes.

c. TYPICAL INSTALLATION. Multiple-engine airplanes are provided with engine-driven vacuum

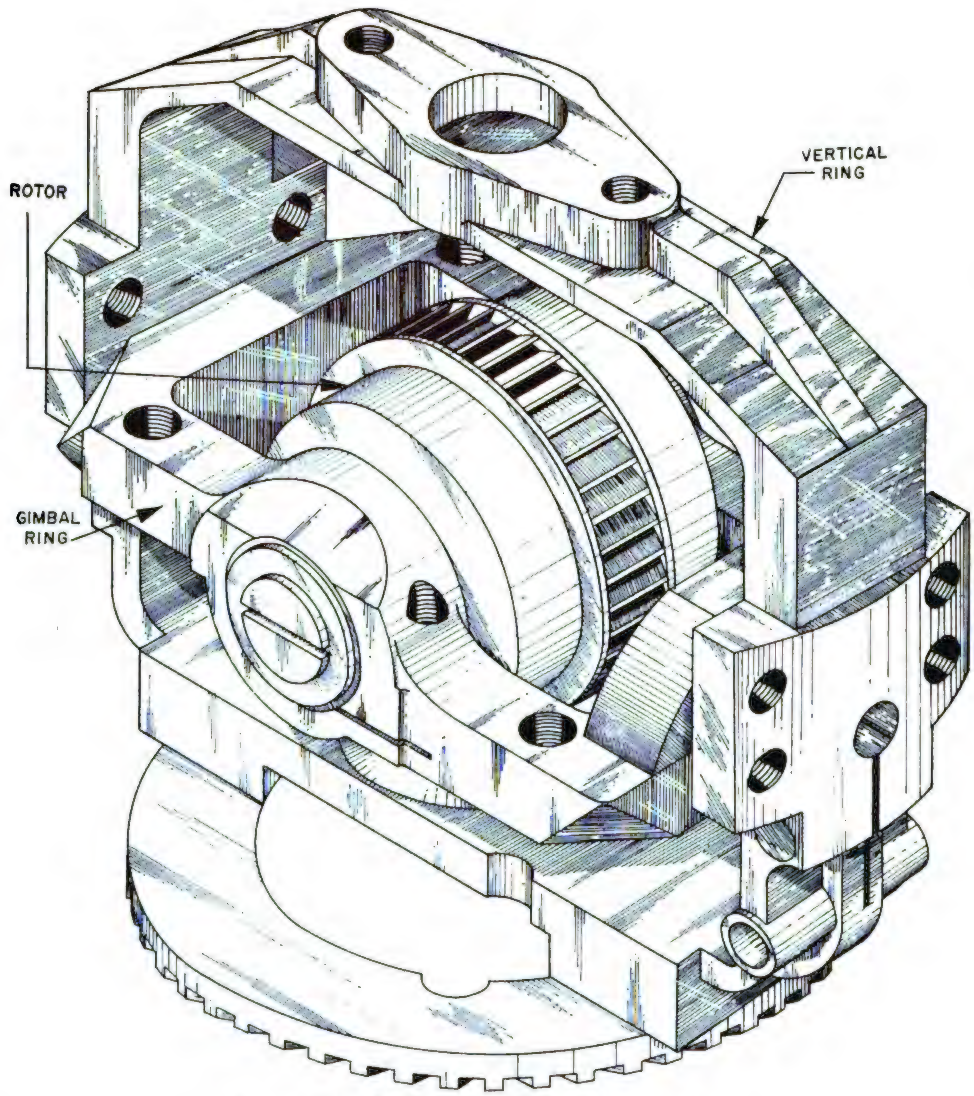


Figure 121. Gyroscope mounting—directional gyro.

pumps installed in the accessory sections of at least two engines. (See fig. 125①.) A single-engine airplane is provided with one vacuum pump. The venturi tube is generally installed on observation aircraft, primary training aircraft, and gliders, to afford a source of suction for the turn-and-bank indicator. (See fig 125②.) The tube is mounted with the arrow on the nameplate pointing in the direction of flight. It must be placed where it receives an unobstructed flow of air (in the slipstream of the airplane propeller) and as close as possible to the instruments it operates, where the length of connecting tubing will be at a minimum. Necessary bands in the tubing must be smooth and have a radius of not less than 3 inches.

(1) For a gyroscopic instrument operated by an engine-driven vane type vacuum pump, shown in figure 125②, a vacuum-relief valve may be supplied as a part of the pump or as an accessory to the pump. This unit limits the vacuum supplied to the instrument to 4 inches Hg in spite of high pump speeds. The valve contains a spring-controlled disk that opens to admit air at the maximum suction required. It should be placed screen side down in such a location that the intake screen is accessible for cleaning or replacement, and the vacuum-adjustment screw for setting.

(2) A check valve may be provided as an integral part of the pressure-relief valve, or it may be included in the system as a separate unit, to prevent injury to the instruments due to engine kick-back, or used in installations, such as shown in figure 125①, to automatically close off one line in case of engine or pump failure.

(3) A vacuum-selector valve is provided in the system close to the instruments to permit changing

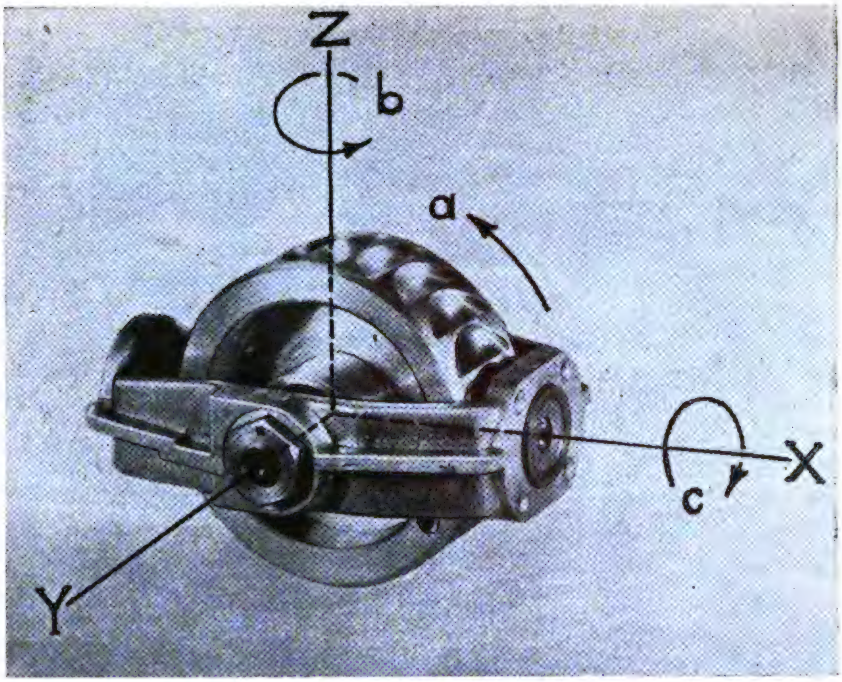


Figure 122. Gyroscope rotor—bank-and-turn indicator.

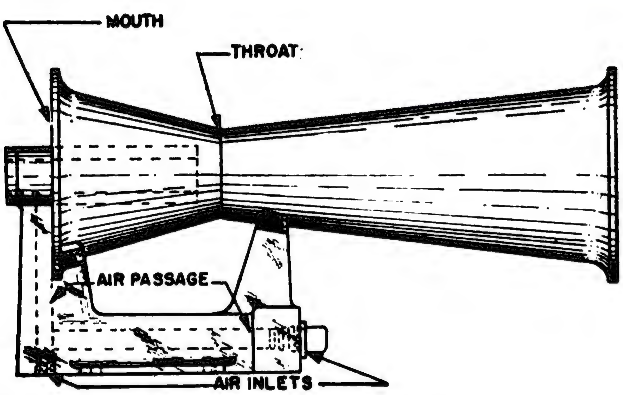


Figure 123. Venturi tube.

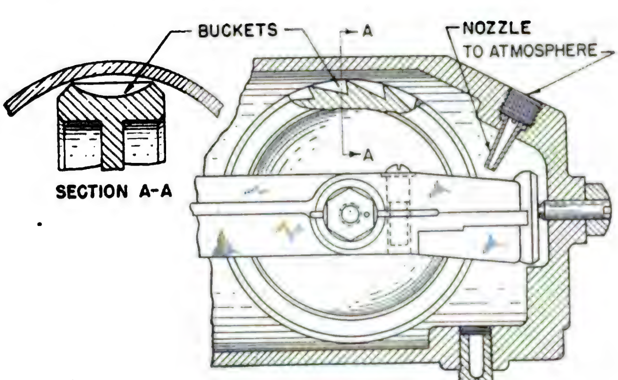


Figure 124. Gyroscope showing nozzle and buckets.

from one source of suction to the other when necessary.

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(4) A suction manifold is employed to distribute the suction to the various gyro instruments.

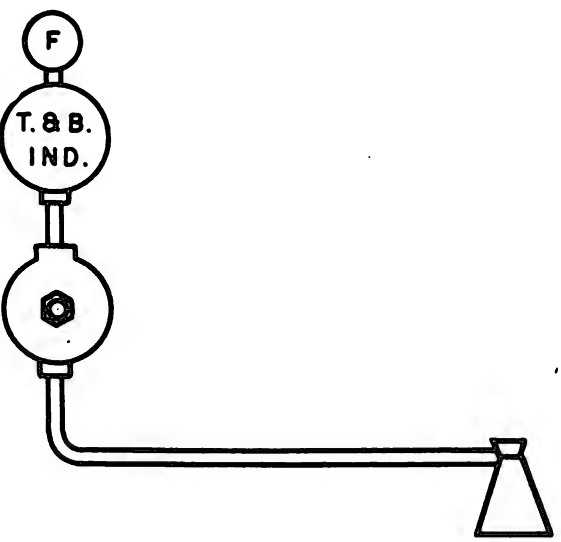
(5) A needle or vacuum-control valve is included in the line leading to the bank-and-turn indicator to control the amount of suction being supplied to that instrument.

(6) A suction gauge is provided to show whether the instruments are operating at the proper vacuum. The suction gauge is connected differentially across the flight indicator and also indicates lack of sufficient air flow due to a clogged-up air filter or a restriction in the suction lines to the instrument.

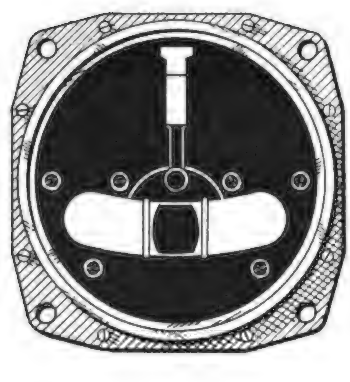
(7) The air for operating the instruments is drawn from the cockpit or cabin of the airplane. Dust deposits from the air effect the operation and shorten the life of the instruments. On later model airplanes, all the air for driving the gyro rotors is passed through a single common air filter.

53. Bank-and-Turn Indicator

a. GENERAL. The bank-and-turn indicator (fig. 126) is used for controlling the flight of an aircraft under conditions of poor visibility, or when it is desirable to eliminate yawing or turning. By reference to the indicator the pilot is able to maintain a laterally level attitude of the airplane while flying straight and to bank at the proper angle when turning. The instrument is a combination of two flight instruments, a bank indicator and a turn indicator.

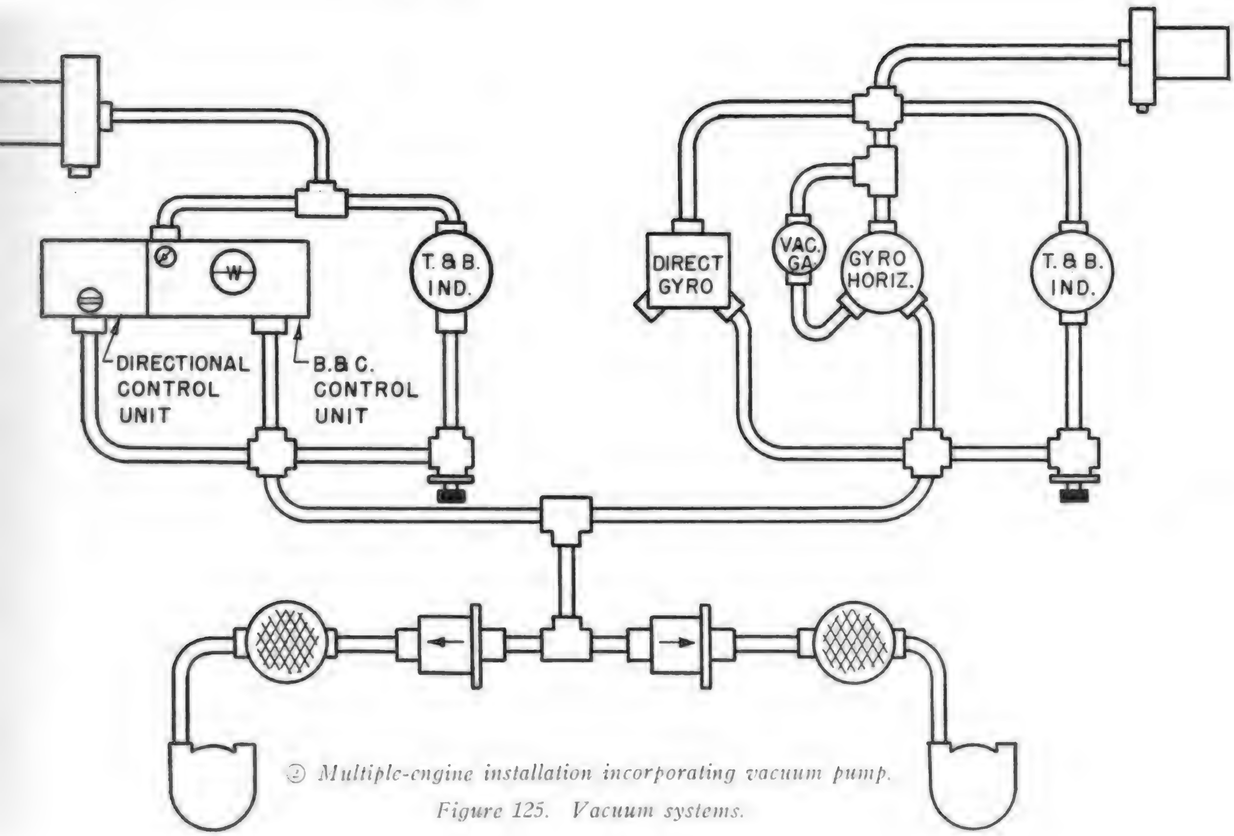


① *Installation incorporating venturi tube.*



STRAIGHT AND LEVEL

Figure 126. Bank-and-turn indicator.



② *Multiple-engine installation incorporating vacuum pump.*

Figure 125. Vacuum systems.

b. TURN INDICATOR. (1) In the turn-indicator it, the application of suction to the instrument se causes a stream of air to flow into the case rough the air-filter assembly and an intake jet. e stream of air is directed against the buckets of gyro wheel, driving it at a speed of approxi- tely 12,000 rpm. The wheel (fig. 122), carefully lanced, runs on specially designed precision ball bearings, to which oil is supplied from a reservoir within the gyro. The gyro rotates about the lateral axis. *Y* (fig. 122) in a frame that is pivoted about the longitudinal axis *X*. When mounted in this manner, the gyro responds only to motion around a vertical axis, not being affected by rolling or pitching. When the airplane is turning, for example, to the left, the gyro assembly is rotated as indicated

ıe arrow, since the X axis is fixed to the longi-
ıal axis of the airplane. The reaction of the
to this turning influence is rotation about the
xis. This movement, known as precession (par.
2)), is the tendency of the gyro to react at
angles to an applied force. In the turn indi-
the rotation of the gyro assembly around axis
cts against a restraining spring force and is
ed by stops to about 45° each side of the vertical.
spring serves to balance the gyroscopic reac-
during a turn and to restore the assembly to its
cal neutral position as soon as straight flight
sumed.

) The action of the gyro assembly is damped
dash pot (cylinder and piston assembly). An
ing provided in the interior of the cylinder is
rolled by a screw-valve adjustment to provide
ecessary damping. Both sensitivity and damp-
djustments are accessible through screws from
outside of the case. The combined effects of
, spring, and damping mechanism produce a
acement of the gyro assembly approximately
ortional to the rate of turn of the aircraft. This
acement is transmitted to the pointer by a link-
system. When centered, the indicator pointer—disregarding drift, pitch, and bank—shows that the airplane is flying straight. When the pointer is off center, it indicates that the airplane is turning in the direction shown by the pointer. The amount that the pointer is off center is approximately proportional to the rate of turn. It has been found that satisfactory turning indication is secured if the centralizing spring is so adjusted that the deflection is one pointer width when the airplane makes a turn of 180° in 60 seconds.

c. Bank Indicator. The bank-indicator unit (ball inclinometer) is a simple form of pendulum consisting of a black glass ball which moves against the damping action of a liquid in a curved glass tube. Its primary function is to indicate proper aileron application for a given rate of turn, thus making it possible for the pilot to prevent either "skid" or "slip." Figure 127 illustrates indications of the unit under various conditions of flight. The unit is so constructed that when the airplane is flying straight and level, the ball (because of its own weight) takes a position in the center of the tube. During a turn, centrifugal force tends to make the ball roll outward, while gravity tends to make it roll inward. In a correctly banked turn, the resultant of these

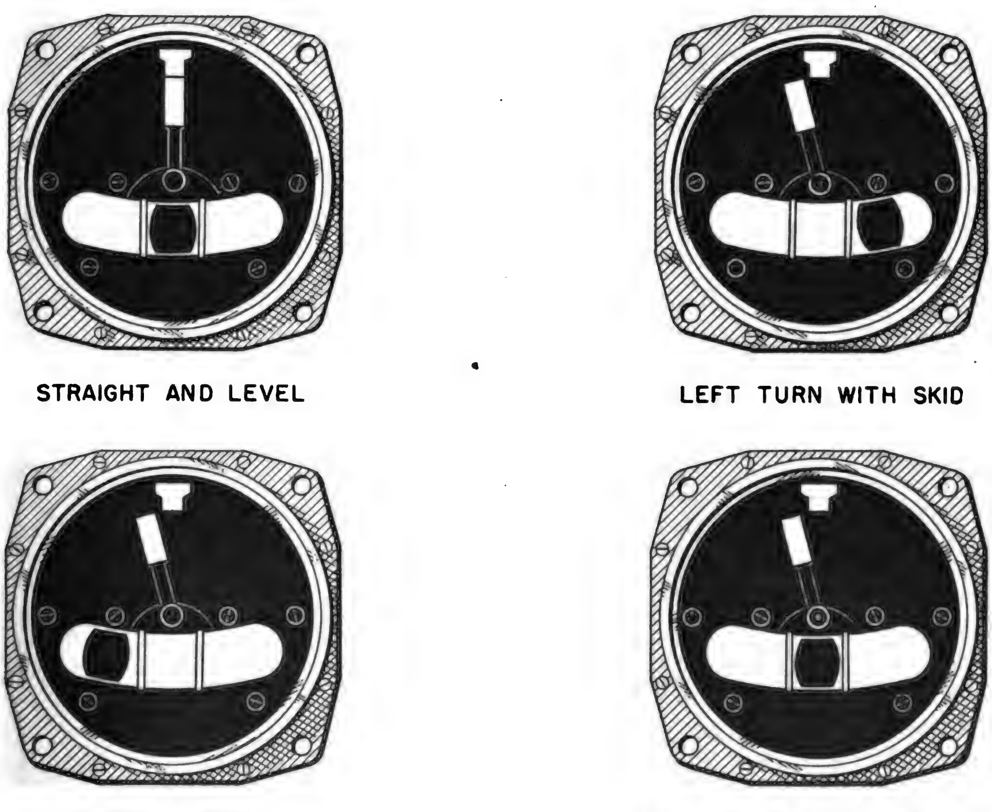


Figure 127. Indications of bank-and-turn indicator.

two forces runs through the center of the tube and hence causes the ball to remain at the center. If the ball moves inward, the airplane is slipping toward the inside of the turn. (Slipping results when the airplane is banked too much for the turn.) If the ball moves outward, the airplane is skidding toward the outside of the turn. (Skidding results when the airplane is not banked enough.) The correct bank is thus indicated for any turn, but no indication is given of the amount of bank. If either straight flight or a turn, the centered ball indicates only whether the lateral attitude of the airplane is correct.

d. ACCESSORY PARTS. The bank-and-turn indicator (fig. 128) includes vacuum connections, a damping adjustment, a sensitivity adjustment, a lubrication opening, and an indicator dial.

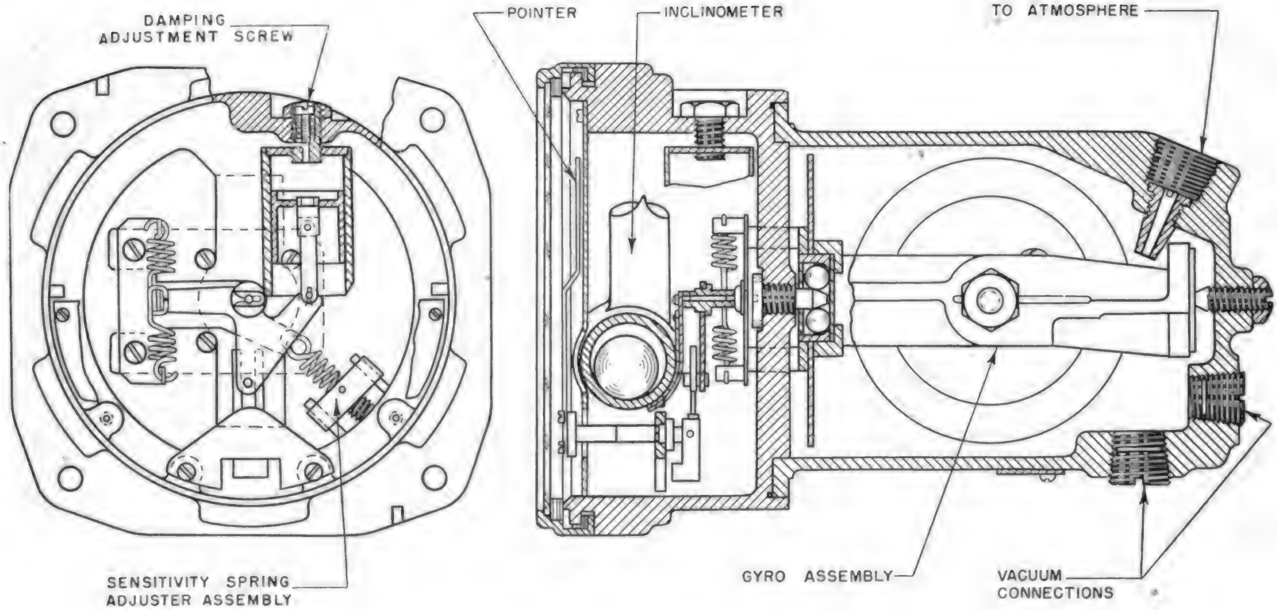


Figure 128. Bank-and-turn indicator mechanism.

(1) One vacuum connection is located on the bottom of the rear of the case, and the other at the back. Both have ⅛-inch internal pipe threads and are provided with pipe plugs, so that either may be removed to connect the vacuum line, depending upon the convenience of the installation.

(2) The damping adjusting screw is located in the counter bore of the lock nut, on the top of the front ring, behind the mounting flange. When the screw is turned inward, the open area of the damping orifice is increased and the damping effects decreased. Turning the screw outward will serve to dampen the mechanism to a greater extent.

(3) The sensitivity adjusting screw and lock nut are on the lower right-hand side of the front ring behind the mounting flange assembly. When this screw is turned inward, the tension on the centralizing spring is decreased, permitting the rate-of-turn pointer to deflect farther for a given rate of turn. Turning the screw outward decreases the sensitivity of the instrument.

(4) The lubrication opening (marked "Oil") is on the righthand side of the rear section of the instrument case. It is provided with a threaded plug and a lead gasket for sealing purposes. Eight drops of specified instrument oil are applied. A fine wire should be used to guide all the oil into the opening.

(5) Indicator dials vary, generally depending upon the type of indicator used. One type has the letters *L* and *R*, the neutral mark, and index marker on each side of the neutral mark. The index marker indicates a turn of 360° per minute when the pointer coincides with it. Another type of dial carries the neutral mark and the two index markers, omitting only the letters. A third type of dial may carry only a neutral mark and omit both the letters and the index markers.

54. Directional Gyro

a. GENERAL. The directional gyro establishes a fixed reference for maintaining the direction of flight. It may be used to supplement the compass in keeping a course, to show the magnitude of turn, or as an aid in compensation and correction in the "air swinging" of the compass. It aids in instrument landings and in the location of radio-beacon stations.

b. DESCRIPTION. (1) The directional gyro indi-

cators now being installed on Army Air Forces airplanes are essentially of one type (fig. 129), although those made by different manufacturers may differ in minor structural details. Older type directional gyros may be encountered on some older airplanes. Since these operate on the same principle as the new ones, their insepection and care should present no special problems for mechanics familiar with the newer type.

Figure 129. Directional gyro.

(2) The instrument in figure 130 contains a rotor which is air-driven on a horizontal axis at about 12,000 rpm. Air to operate the rotor enters through the screened opening around the bearing pivot on the bottom plate of the instrument. The air is directed through a jet nozzle onto the buckets in the rim of the rotor. If the rotor tilts, the air stream strikes the outer edges of the rotor buckets. This jet of air is responsible for righting the rotor. A vacuum pump draws the air from the instrument case and operates the instrument at a vacuum of 4 inches Hg.

(3) The rotor is provided with an azimuth card, graduated in degrees. The rotor is universally mounted; that is, it is supported in a gimbal ring which is free to turn about an axis on bearings in the vertical ring, and the vertical ring is free to turn about the vertical axis. A circular card attached to the vertical ring indicates the degree of turn. The card is observed with reference to the lubber line through the rectangular opening in the front of the instrument case.

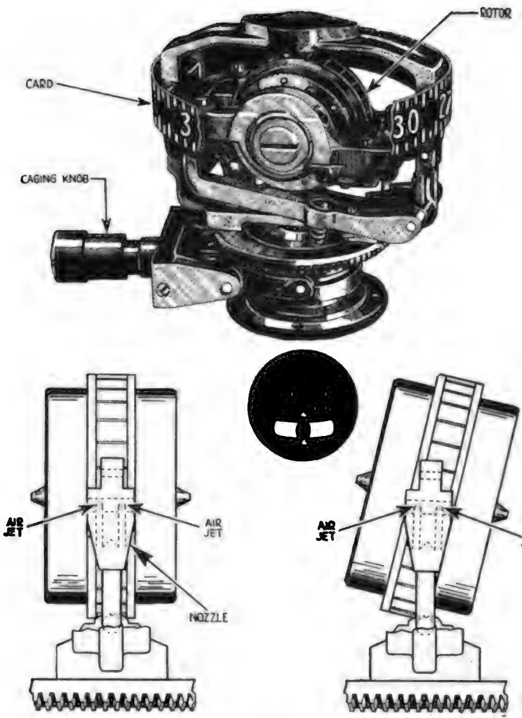
(4) The entire assembly is supported and carried on pivots and bearings mounted in the top and bottom plates of the instrument case. The caging knob, for setting the gyro heading, projects through the front of the instrument case underneath the dial. The instrument case is cast of aluminum or magnesium, the rear cover being held to it by means of filister-head machine screws. The case is sealed airtight at all points except at the suction connections and at the air inlet. Two ¼-inch pipe-tapped openings are located on the bottom plate near the rear and one at the top rear for insertion of suction connection nipples. One ¼-inch pipe connection is provided in the center of the back cover for connection to the central air filter. Some models of indicators have (on the face) ball inclinometers which are used for banking purposes, but on all recent instruments this feature has been omitted.

c. Operation. (1) Starting the engine starts the operation of the vacuum system, which drives the rotor of the instrument. If a vacuum pump is used, the rotor will require about 5 minutes to come up to speed. If a venturi tube alone is used, the rotor will not come up to speed until 3 or 4 minutes after take-off.

(2) In a straight and level flight, the rotor spins in its vertical plane in the direction of flight, and the reading on the azimuth card does not vary from its original setting. When the airplane turns, with the usual bank, the instrument case tilts with it. Precession of the rotor (rotation at right angles to its axis) is prevented by the air jet as previously described, and tilting of the rotor, because of the bank, is prevented by the turning of the gimbal ring about its horizontal axis. Due to rigidity of the gyro, the vertical ring rotates on the vertical axis and so permits the rotor to continue spinning in the former direction of flight. The azimuth card, attached to the vertical ring, thus is displaced with respect to the indicator scale, and the amount of turn is indicated.

(3) The instrument is read like the pilot's (type B) compass. It makes possible more accurate directional control than the compass because it does not swing or oscillate. It provides as positive a reference for steering as objects on the natural horizon.

(4) Unlike a compass, the directional gyro is not in itself north-seeking and has no directive force to return it to a fixed heading. The instrument must be checked occasionally and if necessary reset to correspond to the compass heading, or it may be set on zero when the amount of turn from any established heading is being measured. This heading is set by means of the caging knob. Pushing the caging knob inward raises the caging arm so that it makes

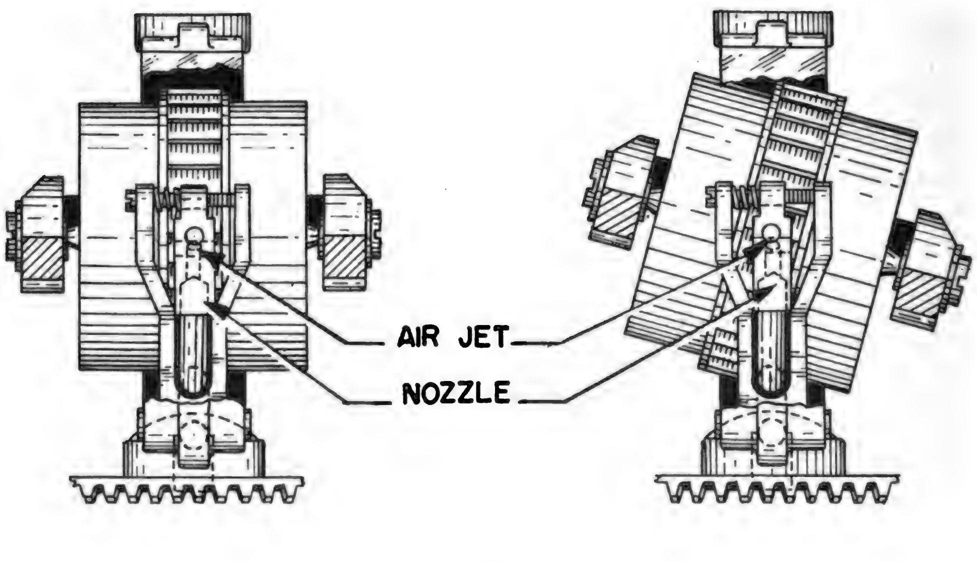


①

after the instrument is in operation unless it is ei
upset or recaged.

(5) The gyro must be set originally to the m
netic compass and reset at intervals from 15 t
minutes to correct the "drift" of the gyro. I
is the tendency of the gyro rotor to precess or
away from the heading due to internal frictio
because of the earth's rotation. The average
on cardinal headings should not exceed 3° in
minutes, and the drift on any single heading sh
not exceed 5° in 15 minutes.

(6) Care should be taken when setting or
setting the directional gyro, especially in rough
to be certain that a correct compass readin
obtained. Even during straight flight, in rough
the magnetic compass will swing to a certain ex
When the magnetic card appears to be still,
actually at the end of a swing and therefore far
from the true magnetic heading. If the directi
gyro is set to the magnetic compass at one end
swing and observed a short time later in conne
with the compass when the compass is at the opp
end of a swing, it will seem as though there had



②

Figure 130. Directional-gyro mechanism.

contact with the bottom of the gimbal ring and holds the rotor horizontal. By turning the knob, the card can be turned to the desired heading. Pulling the caging knob outward, after setting the card with the airplane level, releases the caging mechanism and leaves the gyro horizontal and free. There-

excessive drift of the gyro. To avoid this tro
the airplane should be held as straight as pos
for about a minute, by a directional gyro set
approximately the same as the compass rea
During this time the compass may be observe
determine its average reading during swings.

directional gyro may then be properly set. When the gyro is uncaged after setting, the caging knob should be pulled straight out.

(7) Any amount of climb, dive, or bank exceeding 55° will upset the gyro, and in all probability the card will start to spin. Consequently the instrument is useless until the airplane is again leveled and the gyro caged, reset, and then uncaged again. If acrobatics are to be performed, the gyro should always be caged during maneuvers which would exceed the operating limits. At all other times, the gyro should be uncaged. The precision pivots and bearings will thus be less subject to damage and the life of the mechanism will be increased.

(8) On the latest designs of directional gyros, a novel method of erection has been employed. This method may be called "plowshare" erection. The rotor is inclosed in a housing. The jet of air to drive the rotor is pulled through the housing by the vacuum pump. The air is exhausted from the housing through a tube toward the bottom of the instrument. The exhausted air from the tube strikes the edge of a plowshare-shaped device attached to the vertical ring. If the gyro is erect, the stream of air from the exhaust tube is exactly bisected by the plowshare, so that the same force is exerted on both sides. If, however, the gyro tilts, more air strikes one side of the plowshare than the other. This unequal distribution of air causes a precessive force to be applied to the vertical ring, causing the gyro to erect.

55. Gyro Horizon

a. General. The natural horizon is the reference which a pilot would instinctively use in flight. When the natural horizon is obscured, the gyro horizon (fig. 131) provides an artificial horizon within the cockpit of the airplane. The miniature airplane and the gyro-actuated horizon bar of the indicator provide the pilot with a simulation of what he would normally see outside the airplane. At all times the instrument shows the attitude of the airplane's flight with reference to the real horizon and consequently the ground underneath it. By its use, the pilot is able to measure the amount of bank when making precision turns, and to maintain the proper glide angle during the approach to the runway when he is making an instrument landing.

b. Description. (1) The instrument contains an air-driven rotor universally mounted, that is, so mounted that its axle can assume any position in space. The rotor is mounted in a housing (fig. 132) and, when spinning, maintains its axis of spin re-

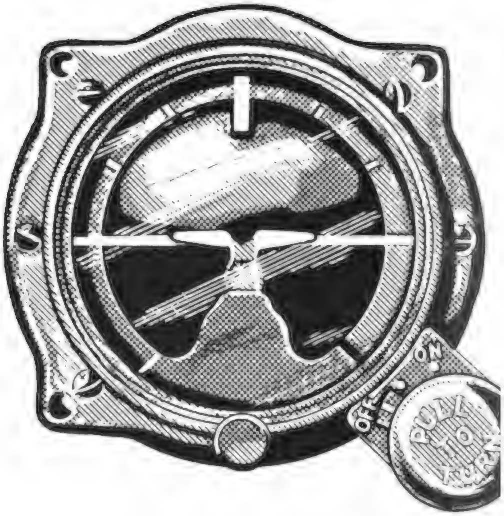


Figure 131. Gyro horizon.

gardless of the airplane's movements so that a h zontal flight reference is established. Any moven of the airplane about the X or Y axis is shown the indicator face by the horizon bar. This ba actuated through linkage by means of a pin truding from the gyro housing through a slot the gimbal ring. The bar is observed by the p with reference to the miniature airplane, which part of the dial on the front of the instrument.

(2) Air enters the air pivot at the rear of gimbal ring, flows through a passage in the and then through the air pivot in the side of gyro housing, and is directed against the buckets the rotor, causing it to spin. The air is drawn of the rotor housing through four air ports, of which is shown in figure 132 in the pendul body.

(3) Because of bearing friction, the gyro a tendency to tilt or precess. This is prevented governing the flow of exhaust air from the air po Four pendulous vanes are balanced in opposite p by the balancing nuts so that when the gyro is normal position the vanes bisect the ports, leav them half open. (See fig. 133.) When the g begins to depart from normal position, one vane close its port and the opposite one will open its p (See fig. 133.) The reaction of the air from open port moves the gyro back to the normal posit

(4) Because of forces of acceleration acting the vanes, a turn of the airplane tends to displ the gyro and thus cause the horizon bar to slightly. This tendency is offset by erecting the g so that the top of its spin axis is normally incli 2½° forward from the vertical axis. This incli

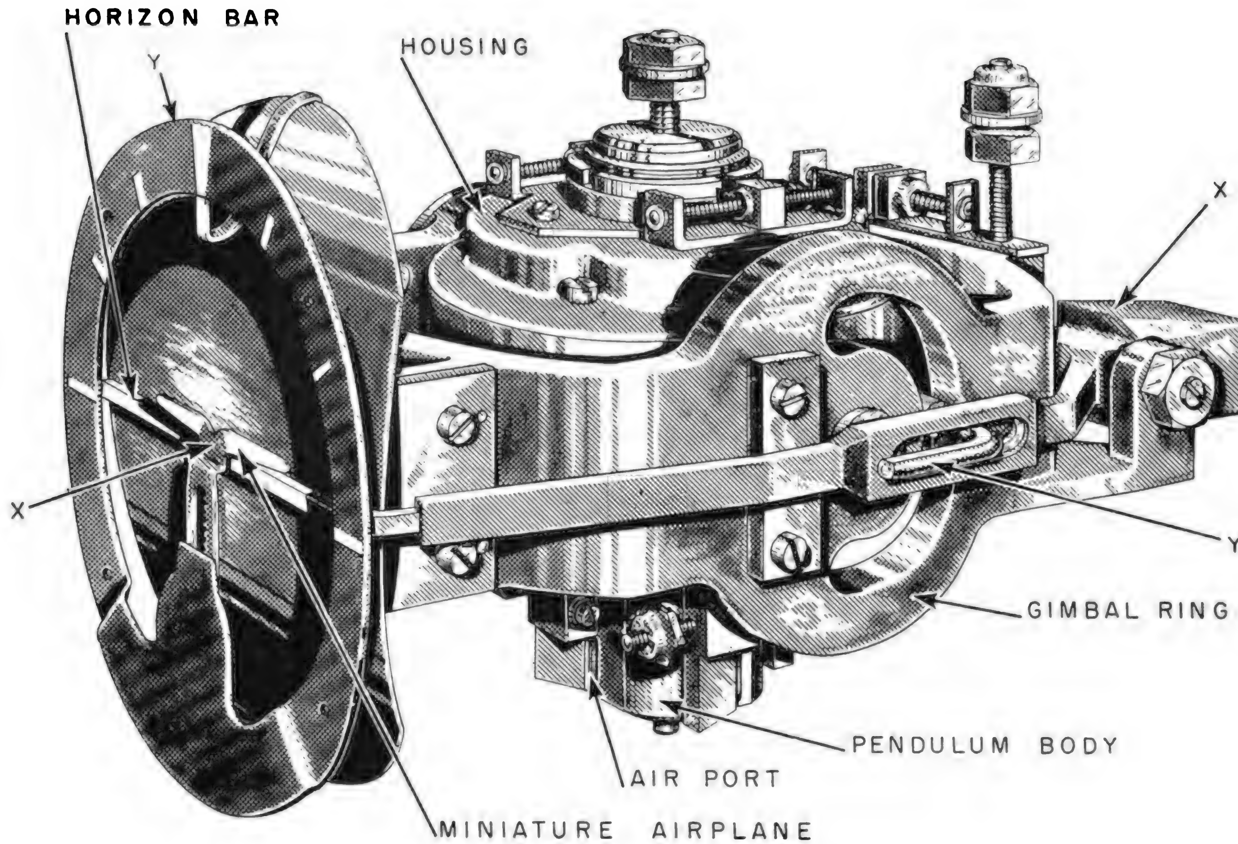
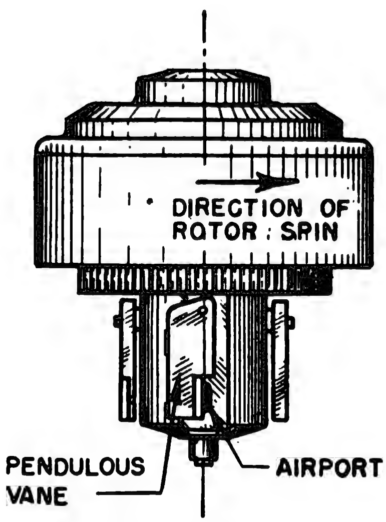
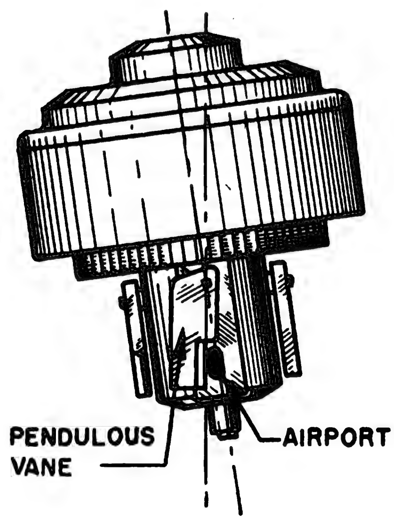


Figure 132. Gyro-horizon mechanism.



① *Gyro in normal position.*



② *Gyro out of normal position.*

Figure 133. Operation of pendulous vanes.

tion compensates for the errors that would result from the standard-rate turn of 180° per minute.

(5) Gyro horizon indicators are provided with caging devices to prevent damage to the gyros during acrobatics and similar maneuvers in the air which exceed the operation limits of the instrument. The caging knob is located at the lower right-hand corner of the instrument case. The knob is marked "Pull to Turn" and has a shield inscribed with a reference line. On some indicators there is a dial with position marked "On" and "Off." To cage the gyro, the caging knob is pulled out, turned to the "Off" posi-

tion, and then pushed in to engage the detent pin. In this position, the reference line points to the "Off" position and the shield on some models exposes a warning dot on the right-hand side of the caging dial to show the pilot that the gyro is caged and the instrument is not indicating. To uncage the gyro, the caging knob is pulled out, turned to the "On" position, and then pushed in to engage the detent pin. In this position, the reference line points to the "On" position and the shield covers the warning dot, showing the pilot that the instrument is indicating. Make certain that the warning dot is completely covered; otherwise the gyro is not entirely free or uncaged.

(6) Some gyro horizon indicators have arrows on the small dials instead of the "On-Off" markings. However, the procedures for caging and uncaging the mechanism are similar in operation.

(7) The horizon bar is covered with luminous material to make it visible at night, and the dial is finished in satin black. The banking indicator, the pointer, and the scale are also covered with luminous paint. The instrument case is an aluminum or magnesium casting with removable front and rear plates for insertion and removal of the mechanism. Four mounting lugs with self-locking lug inserts are provided for mounting purposes on the panel. Tapped openings are provided in the rear of the case for attachment of the suction connections and central air filter. When the instrument is not installed, ¼-inch pipe plugs are screwed into the openings to keep out dirt.

c. Operation. (1) Starting the engine starts the vacuum supply, which spins the gyro. The gyro comes up to speed in about 5 minutes. The vacuum should be 3.75 to 4.25 inches Hg. If the vacuum is supplied by a venturi tube, 3 or 4 minutes will be required after take-off to bring the gyro up to speed.

(2) The horizon bar remains parallel to the natural horizon through all the maneuvers of bank, climb, glide, or turn. It has no time lag, and the pilot can manipulate this control to bring the airplane to any desired attitude by noting the relation of the miniature airplane with reference to the horizon bar.

(3) If the airplane banks or rolls, only the external case and the miniature airplane are carried with it. The gyro, the gimbal ring, and the horizon bar remain level. The pointer, attached directly to the gimbal ring, indicates the amount of bank in degrees on the scale.

(4) If the airplane pitches or otherwise changes its fore-and-aft position with reference to the horizontal plane, the case tilts on its axis and the horizon bar is rotated about its pivot. The position of the bar, in relation to the miniature airplane, indicates the amount of fore-and-aft tilt of the airplane. Figure 134 shows the flight indicator during various attitudes of flight.

(5) In level flight, the angle of attack of the airplane varies according to changes in airspeed or in total weight of the airplane. Thus the normal position of the horizon bar varies also. To compensate for these changes, the miniature airplane may be adjusted, by means of the knob at the bottom of the horizon dial, to match the horizon bar.

(6) The limits of operation of the gyro horizon are 70° of climb or dive, and 100° of the left or right bank. If at any time the attitude of the airplane exceeds these limits from the horizontal around either or both the longitudinal or lateral axes, the instrument will be upset and its indications will become erroneous. Consequently the instrument is useless until the airplane is again leveled and the gyro caged in order to level the mechanism properly. When the gyro is uncaged, the instrument is ready to use again. The gyro should always be caged during maneuvers which would exceed the operating limits, especially if acrobatics are to be performed. The precision pivots and bearings will thus be less subject to damage and the life of the mechanism will be increased. At all other times the gyro should be uncaged.

56. Universal Attitude Indicator

a. General. The universal attitude indicator (fig. 135) performs the functions of the gyro horizon and has in addition special features peculiar to this instrument. It provides continuous attitude indication throughout all airplane maneuvers, including vertical climbs, dives, and inverted flight. About the lateral and longitudinal axes of the airplane, 360° freedom of indication is possible; therefore, no limit stops or caging devices are necessary.

b. Description. (1) The instrument contains an electrically driven gyro which is inclosed in a spherical housing. A section of this housing may be seen through the circular opening in the front of the case. The upper hemisphere is finished in dull black, while the lower hemisphere is pale yellow. The markings on the upper and lower halves are in contrasting colors to the background; that is, pale yellow on the upper half and black on the lower half. A horizontal reference line runs across the center of the sphere, while short lines run across the

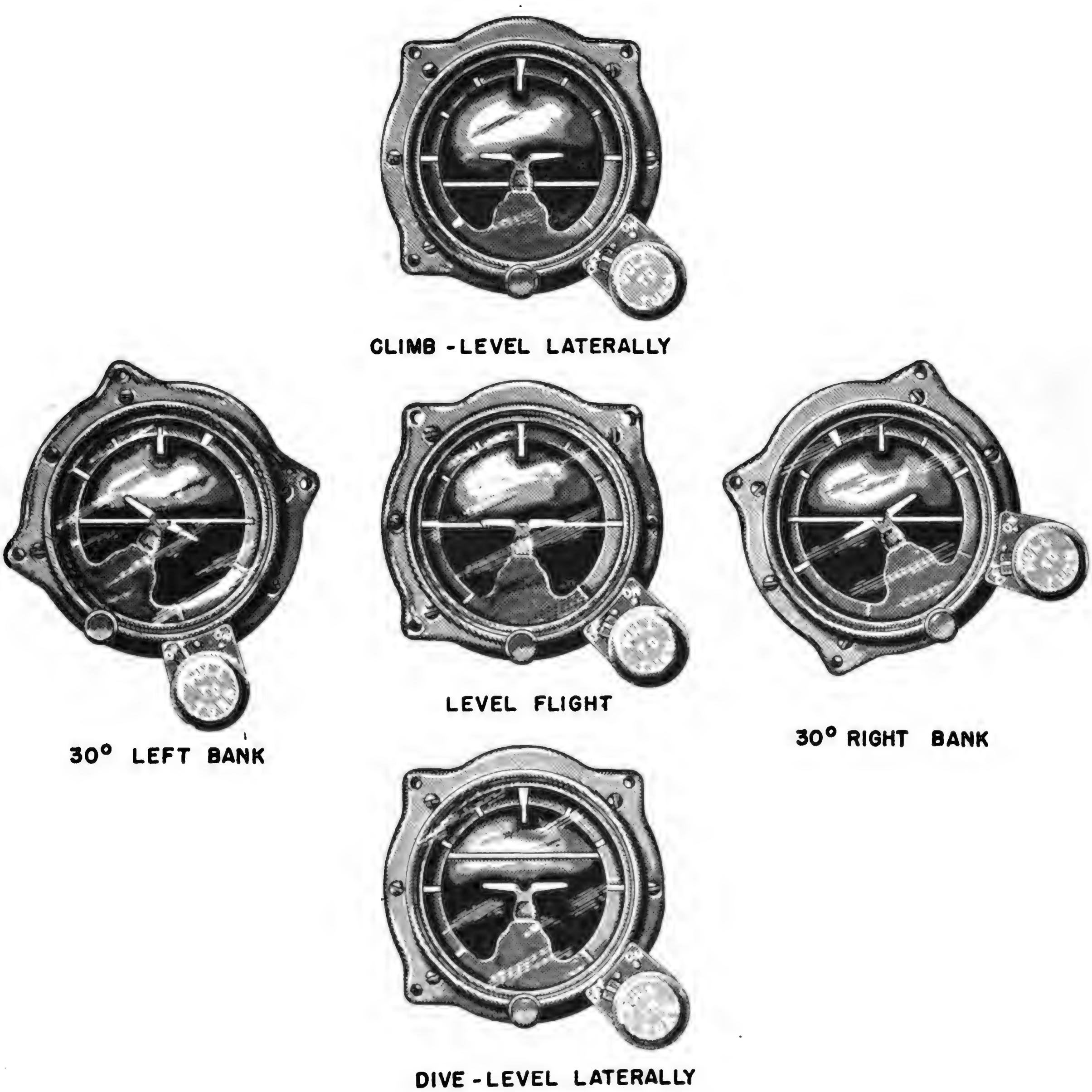


Figure 134. Gyro-horizon indications.

vertical reference line. The words "Dive" and "Climb" appear on the upper and lower halves, respectively, between the 30° and 40° pitch lines. The spin axis of the gyro is, at all times, maintained vertical to the earth. Since the gyro (and sphere) are universally mounted, the gyro maintains its rigidity in space in all airplane maneuvers, while the airplane, instrument case, and consequently the viewing opening move about the sphere. Attitude is viewed by the pilot with respect to an alternately colored dark and light line running horizontally across the center of the cover glass, at the center of which is an index dot. Zero position of the index marker may be varied up and down by means of a knob on the lower front of the instrument. Figure 136 presents cutaway views of the mechanism.

(2) The gyro rotor is operated by 115-volt, 400-cycle, 3-phase, a-c power supply obtained from an inverter. Twenty-eight-volt d-c is also required to energize the friction brake magnet and the erection magnet. A five-contact receptacle is provided at the rear of the case, through which this power is supplied to the instrument.

(3) The friction brake prevents the gyro from tipping over when it is coming to a stop. When the power supply is interrupted or shut off, the friction brake magnet is deenergized, allowing the brake arm to drop down and hold the gyro in the upright position.

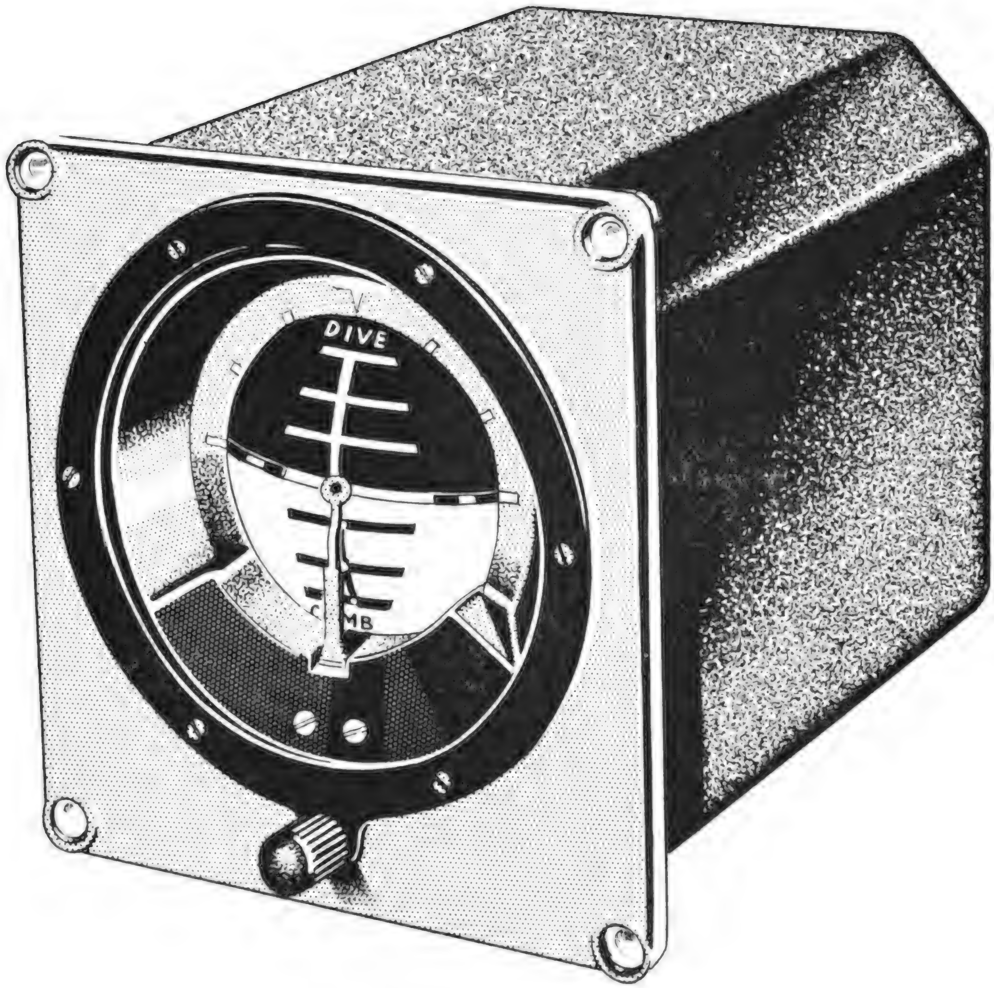


Figure 135. Universal altitude gyro.

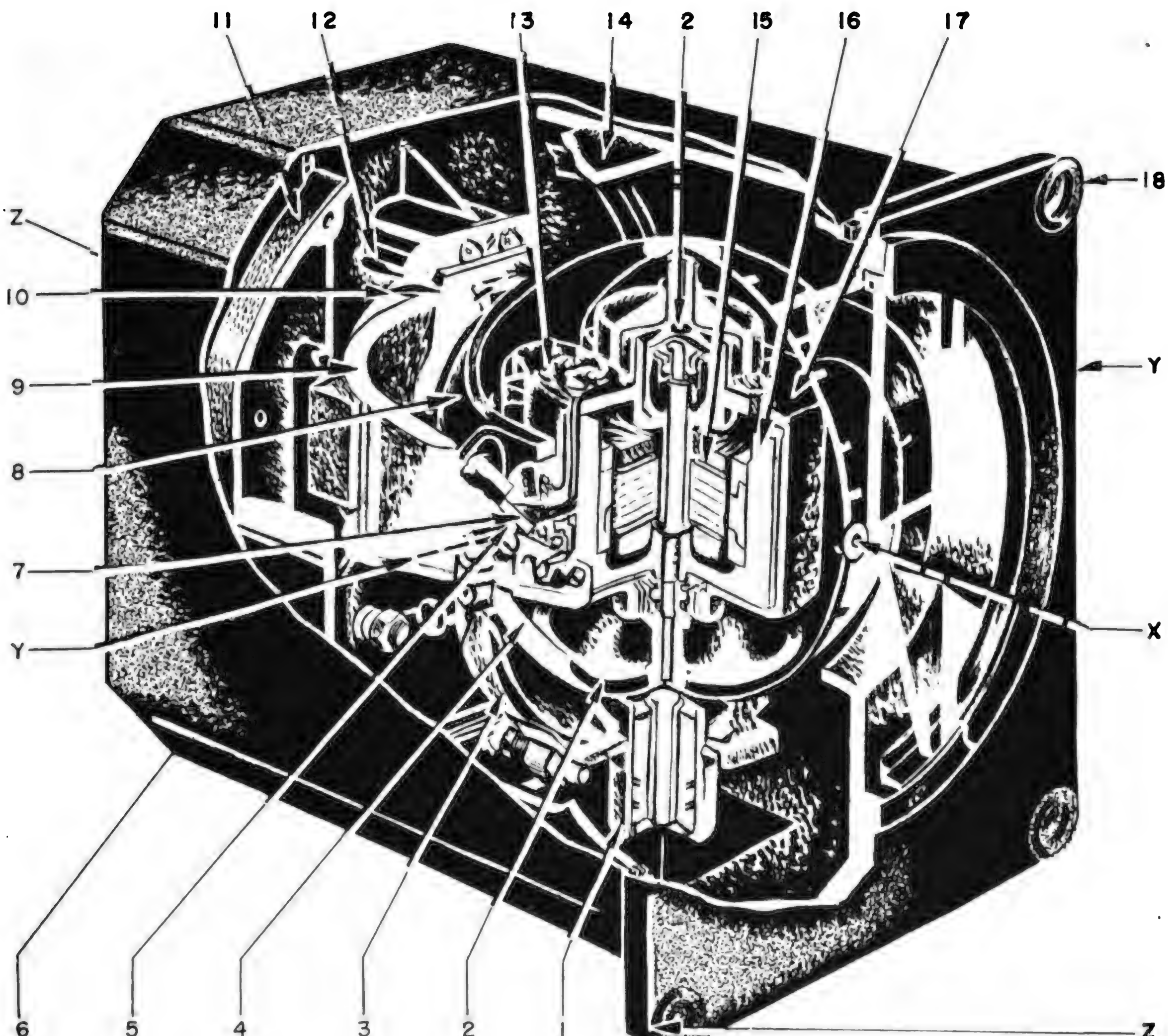
(4) The erection magnet, together with the erection cone, form the mechanism which prevents precessive forces from causing the gyro spin axis to depart from the vertical. The erection magnet is attached to the outer gimbal assembly. An erection cone, resembling an inverted mushroom, is attached to gyro rotor and spins with it. Normally, this cone is suspended directly over the center of the erection magnet. Since the cone rotates in the magnetic field of the erection magnet, emfs are set up in the cone. With the cone rotating in the center of the magnetic field, these emfs balance each other, so no eddy currents are set up. However, if the gyro departs from the vertical, part of the cone will then be in a region of much weaker magnetic flux, so that emfs induced will not be in a state of balance. Eddy currents thus will be set up and, as is true of all induced currents, will create a secondary magnetic field opposing the primary field. Opposition of these fields causes a torque to be applied to the gyro which will precess it back toward the vertical. As the gyro (and cone) come back to the vertical position, the emfs induced again cancel out, stopping flow of eddy currents and consequently the opposing secondary magnetic field.

c. Operation. (1) This instrument is connected directly to the airplane's power supply, with no auxiliary switches or fuses in the line. With the engines running and the master switch closed, power will be supplied to the instrument.

(2) When power is supplied, the gyro starts to rotate. About 5 minutes is required for the rotor to come up to speed. As the friction brake magnet is energized, the brake arms lift, freeing the gyro.

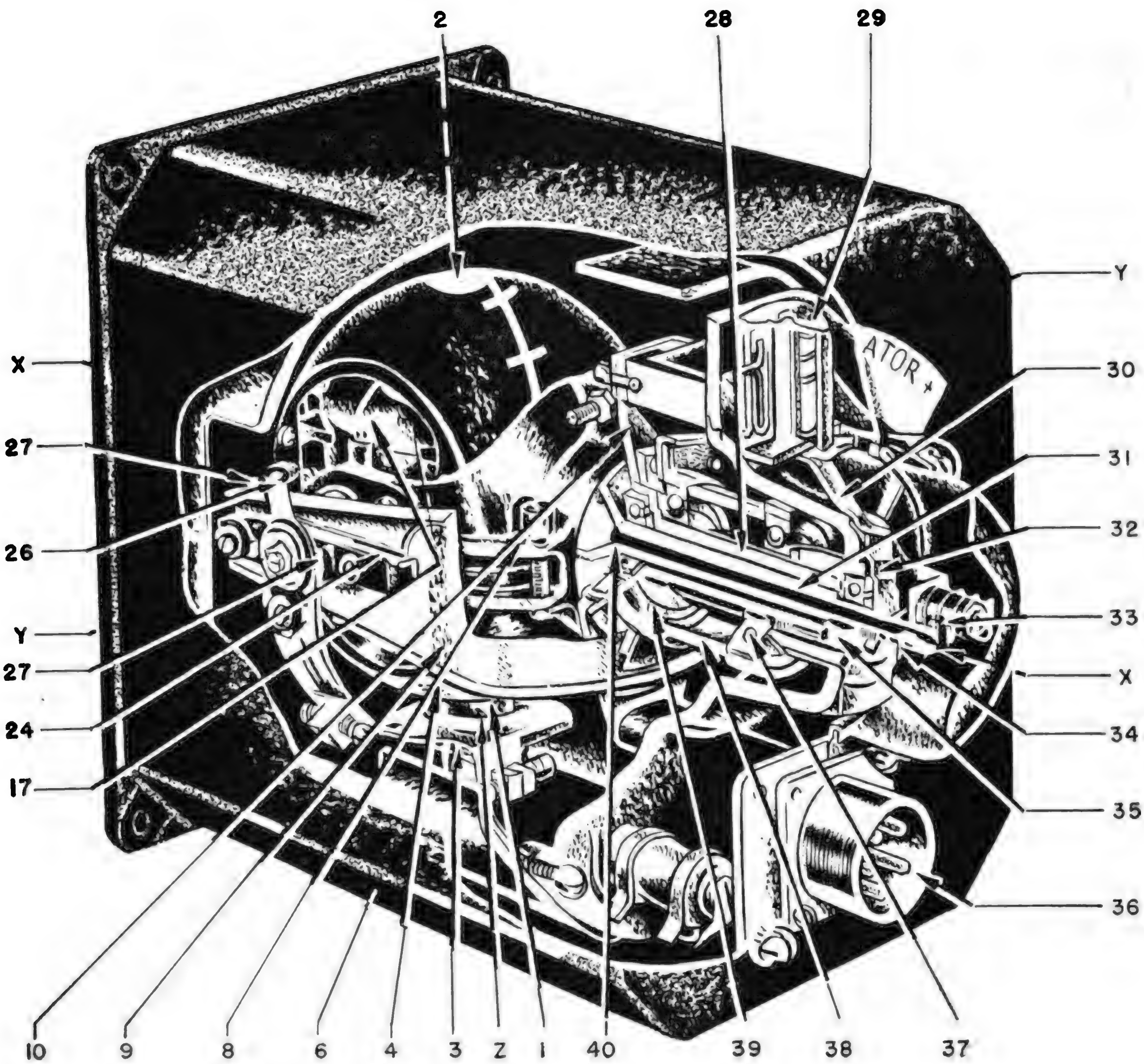
(3) Various pattern indications which might be encountered in flight are shown in figure 137.

(4) During a sustained dive, such as might be encountered in dive bombing, unimpeded operation of the erection system would cause the gyro to erect to a false vertical. An erection cut-out switch in the instrument prevents such an occurrence. When the airplane dives at an angle of 27° or more, an



① *Front view.*

Figure 136. Cutaway views—universal attitude gyro.



② *Rear view.*

1. Erection magnet.
2. Erection cone.
3. Yoke.
4. Indicating sphere.
5. Pivot (yoke).
6. Cover.
7. Contact (gyro power supply).
8. Inner gimbal.
9. Outer gimbal.
10. Shaft retaining ass'y.
11. Back plate.
12. Stop.
13. Terminal block.
14. Chassis.
15. Stator (winding block).
16. Gyro rotor.
17. Gyro housing.
18. Front panel.
24. Contact (erection cut-out switch).
25. Projection (operates erection cut-out switch).
26. Bumper.
27. Stop (yoke).
28. Shaft.
29. Friction brake magnet.
30. Brake lever.
31. Shaft (inner gimbal).
32. Brake plate.
33. Hairpin contacts (gyro power supply).
34. Slip rings (gyro power supply).
35. Bearing (inner gimbal).
36. Electrical receptacle.
37. Bearing (outer gimbal).
38. Outer gimbal ass'y.
39. Bearing (outer gimbal).
40. Bearing (inner gimbal).

Figure 136. Cutaway views—universal attitude gyro—Continued.

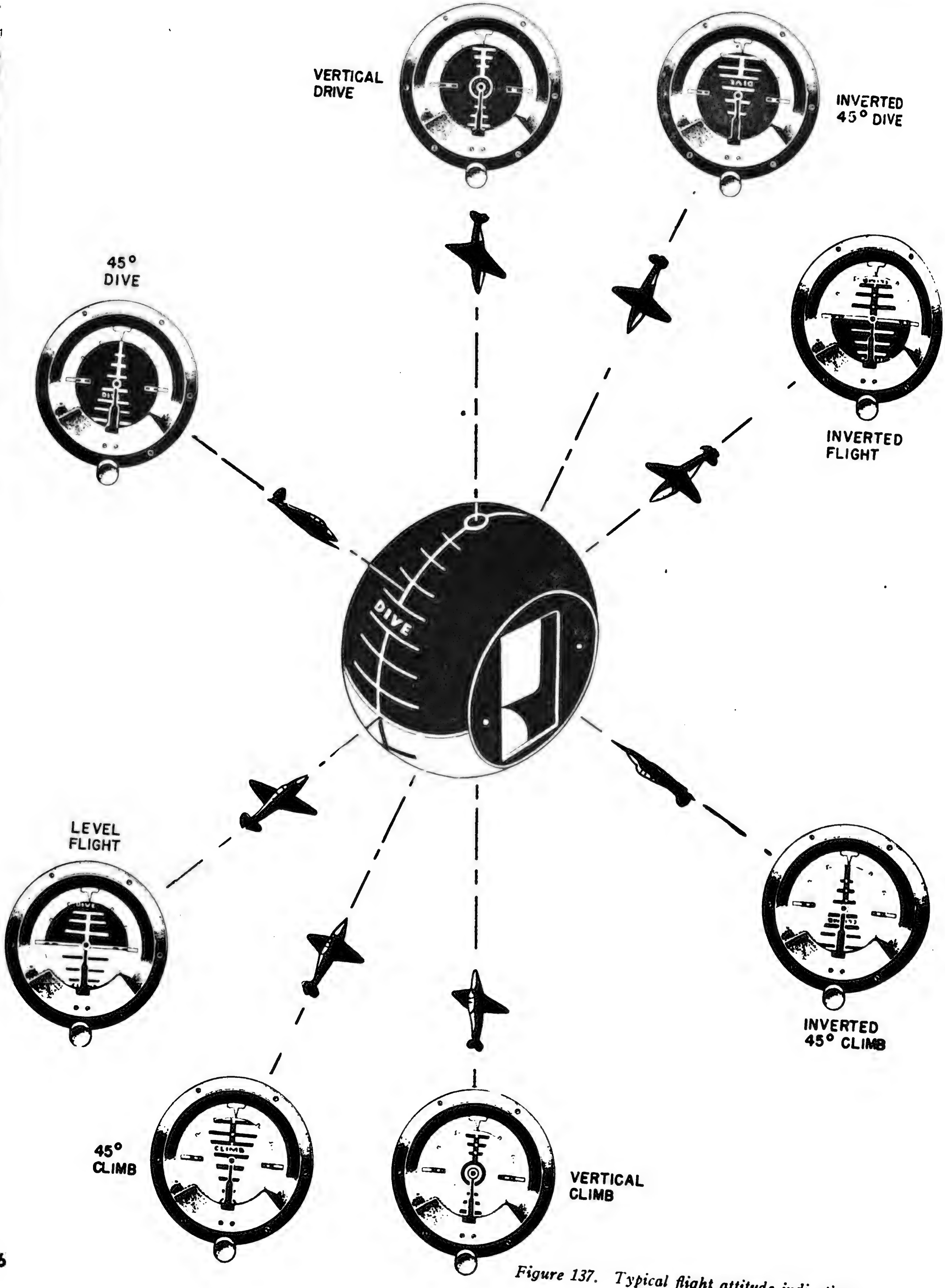


Figure 137. Typical flight attitude indications.

arm on the yoke opens the erection cut-out switch, cutting off current to the erection magnet.

(5) A warning flag is provided in the later models which appears whenever the power supply is interrupted, warning the pilot that the indicator is inoperative.

57. Inspection and Maintenance

a. General. General inspection and maintenance requirements common to all gyroscopic instruments are as follows:

(1) The tubing from the source of vacuum should be run as straight as possible to avoid bends of small radius. It may be connected to the indicators at either of the two connections provided. The connection not used is plugged with the plug provided.

(2) It may become necessary to check the amount of suction inside the instrument case. The check is accomplished by connecting a suction gauge to the indicator connection which is not in use. When a central air filter is used vacuum should be checked with differential vacuum gauge connected across inlet and outlet openings of instrument case. The suction is ground-tested at normal cruising rpm of the engine. The source of suction may be either the vacuum pump on the engine or portable test equipment. Under normal flight conditions, the vacuum produced across the instruments should be not less than 3.75 inches Hg nor more than 4.25 inches. The ideal vacuum is 4 inches at cruising speed. By means of the vacuum control valve, the suction on the bank-and-turn indicator is adjusted to 1.9 inches Hg as closely as possible which should give a deflection of one pointer width as the airplane turns 180° in 1 minute. It should usually not be less than 1.80 nor more than 2.05 inches. Adjustment of the vacuum control valve to secure the desired suction may be made by reaching under the instrument panel. Increasing the vacuum (screwing the valve stem out) increases the sensitivity and amount of deflection. Decreasing the vacuum (screwing the valve stem in) decreases the sensitivity and amount of deflection. If this check shows that the vacuum is less than it should be, the tubing may be kinked, leaking, too long for its diameter, or the suction regulator may be improperly adjusted. If the check shows that the vacuum is excessive, dirt may be clogging the screen of the suction regulator or the suction regulator may be improperly adjusted.

(3) If the instruments still do not function properly, the vibration of the instrument panel and the source of vacuum are checked. If the trouble is found to be due to conditions within the instrument, it should be replaced with one that is serviceable.

(4) Failure of the vacuum pump will register immediately upon the suction gauge. The gauge reading will be less than prescribed. The vacuum selector cock should then be rotated to utilize the alternate source of vacuum. When trouble is experienced by service activities with the vacuum pump, the pump will be removed, forwarded to the depot for overhaul, and a new pump will be installed.

(5) The venturi tube and connecting lines must be clean and free from dust, oil, or other obstructions which may affect vacuum action. Particular attention should be given to the venturi throat since it becomes caked with oil and dirt. To clean the throat, wash it with either gasoline or benzene.

(6) The frequency of cleaning or changing air-intake screens and filters will depend largely upon service conditions. A dirty air-intake screen or air filter will be indicated by a higher vacuum than normal. If the suction gauge is connected across the gyro horizon—the proper method of connecting it—the gauge will indicate less pressure drop.

(7) The common air-filter element should be cleaned or changed whenever necessary. The element is removed from the filter and brushed off with a soft, dry hair brush. Masking tape should be used to cover the holes in each end of the element to prevent dirt from entering during the brushing. One type of filter is built up of hundreds of washer-like disks made from synthetic material. The disks are assembled to form tubes and the air passes from the outside between the disks into the hollow of the tube. To clean this filter, remove the tube assembly from the case and clean with compressed air, or a stiff brush, or wash with gasoline or water.

(8) The common air-filter inlet screen should be cleaned or changed whenever necessary. When removing the inlet screen for cleaning, a long-nosed pair of pliers must be used to remove the snap ring and screen from the inlet hole of the filter. Submerge the screen in clear gasoline and scrub it with a stiff brush. Do not use a wire brush. Then reinstall the screen and the snap ring in the inlet hole.

(9) All plugs and connections must be tight to prevent excessive air consumption.

b. Bank-and-turn Indicator. At regular intervals, bank-and-turn indicators should be checked as follows:

(1) Under ordinary conditions when accumulations of oil or water occur, the instrument will not function properly and should be overhauled. However, at the discretion of the engineering officer of

the station, the drain plug (if provided) may be unscrewed in emergencies to permit the removal of such accumulations so that the use of the instrument may be continued.

(2) The bank-and-turn indicator should be mounted with the other flight instruments, within the unobstructed view of the pilot. It should be mounted so that the dial is vertical when the airplane is in normal level flight and the ball of the bank indicator is in the center position.

(3) To lubricate the bank-and-turn indicator, remove it from the airplane and add oil through a lubricating opening marked "Oil" (on the right side of the case). A fine wire should be used to guide the oil into the hole in the pivot. Excess or spilled oil may be a cause of unsatisfactory operation. For various operating conditions, use oil specified in the latest Technical Orders.

(4) The indicator screen or air jet should be cleaned or changed whenever necessary. Cleaning may be accomplished by first removing the screen from the instrument, washing it in benzene or other suitable cleaning fluid, and drying it thoroughly. For reinserting the screen, a wrench is not necessary; finger-tightness is sufficient. When cleaned, the screen should be thoroughly examined and, if found defective, replaced with a new one.

(5) Give the indicator the static balance test. The pointer must be on zero when the rotor is not spinning, and ±0.015 inch from the correct reading for any position of the instrument.

(6) Give the indicator the dynamic balance test. When the instrument is stationary in the normal position, and the gyro is operated under a suction of 1.9 inches Hg, the pointer should stand at the zero mark or within ±0.015 inch from it.

c. DIRECTIONAL GYRO. At regular intervals directional gyros should be checked as follows:

(1) The shafts, pivots, and bearings are lubricated before assembly in the case at the factory or repair depots, and no further lubrication will be accomplished by service activities. If the caging knob is hard to pull out or push in and turns excessively hard, add a drop or two of instrument oil to the surface of the shaft that passes through the front plate of the instrument case.

(2) The frequency of cleaning the air-intake filter will depend upon service conditions. There are different filters for different instruments. Generally, to clean the intake filter on the bottom of the case a cap must be removed before the filter can be taken out. Then, using a scribe, lift out the snap ring and screen. Clean filter with benzene, dry, and replace. After cleaning, thoroughly examine the filter and, if found defective, replace with a new one. (The filter is not readily accessible when the instrument is installed if the instrument is equipped with an air-inlet adapter for connection to the central air filter.)

(3) To correct functioning of the directional gyro can be checked in position by the use of the drift test. This test checks the balance of the assembly and the condition of the vertical ring bearings. By operating the engine vacuum pump or by connecting a portable vacuum pump into the suction system, the gyro is run on the proper suction for 15 minutes on each of the cardinal headings; that is, 0°, 90°, 180°, and 270°. The card on the gyro should not drift off more than 3° in the 15-minute interval on any of the headings. A drift of 5° is permissible on one heading, provided the average on the four cardinal headings does not exceed 3° in 15 minutes. The portable pump may be connected through the venturi system; the same results may be obtained by disconnecting the line at the engine vacuum pump and connecting the portable pump there, provided the selector valve in the cockpit is set to correspond with the source of entry into the vacuum system.

d. GYRO HORIZON. At regular intervals, a gyro horizon should be checked as follows:

(1) The shafts, pivots, and bearings of the instrument are lubricated before assembly in the case at the factory or repair depot, and no further lubrication will be accomplished by service activities. If the caging knob is hard to pull out, or turns excessively hard, add a drop or two of instrument oil to the surface of the shaft that passes through the front plate of the instrument case.

(2) The frequency of cleaning the air-intake filter in the back of the instrument will depend upon service conditions. First remove the snap ring and screen at the back of the case. Then wash the filter with carbon tetrachloride, dry, and replace. When clean, thoroughly examine the filter and, if found defective, replace with a new one. (The filter is not readily accessible if the instrument is equipped with an air-inlet adapter for connection to the central air filter.)

(3) The suction is checked by using the suction gauge on the instrument panel. When adjustment is necessary, it is made with the suction-relief valve in the vacuum system. When the suction is first applied, the horizon bar will sometimes oscillate violently, which is a normal reaction. However, all

oscillation should cease and the bar settle and hold a steady position after 1½ minutes. The banking indicator must always be perpendicular to the horizon bar; that is, if the bar is turned to the left or right, the banking indicator is off zero the same amount in the same direction.

(4) If the horizon bar fails to respond, a dirty air filter or air screen may be at fault. This condition will result in a high vacuum indication on the suction gauge. When a differential suction gauge is used and the filter gets clogged, the suction will drop off. Examine the clogged air filter or air screen, and clean or replace if necessary. Failure of the horizon bar to respond may also be due to the fact that the instrument is caged, in which case it is necessary to uncage the mechanism. A third cause of failure may be insufficient vacuum, in which case the suction-relief valve will require adjusting.

(5) If the horizon bar does not settle, the cause is possibly due to insufficient vacuum. Adjustment of the suction-relief valve may remedy this trouble. If not, the trouble is due to a defective mechanism, and the instrument must be replaced with a serviceable instrument.

(6) If the horizon bar oscillates or shimmies, the gyro may not be completely uncaged. Excessive vacuum due to improper adjustment of the suction-relief valve or a dirty air filter may also cause this difficulty. Adjust the suction-relief valve or clean or replace the filter. If this does not correct the fault, the trouble is due to a defective mechanism and the instrument must be replaced with a serviceable instrument.

e. Universal Attitude Indicator. (1) Periodic inspection of the indicator consists mainly of checking for cleanliness, broken or loose cover glass, security of mounting, security of connections and discolored or chipped markings.

(2) No maintenance should be required until overhaul ofter 600 to 800 hours of operation. It is advisable to have the indicator removed and bench checked after 300 to 400 hours. Any service troubles will most likely be due to improper power supply or excessive vibration.

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SECTION XII
AUTOMATIC PILOT, TYPES A-2 AND A-3

58. Purpose and Use

a. The automatic pilot is a mechanical means for automatically controlling the flight attitude of an airplane. By its use the human pilot is relieved of the physical effort of flying, since the airplane is automatically kept in level flight and on its course. The automatic pilot allows the attention of the human pilot to be devoted to navigation and tactical problems, engine operation, and other important flight duties.

b. In addition to maintaining mechanical control, the automatic pilot indicates the attitude of the airplane in yaw, pitch, and bank.

59. Principle of Operation

a. The operating principles of the types A-2 and A-3 automatic pilots are the same. Two gyroscopes are mounted so that they cause the opening or closing of air valves when the attitude or heading of the airplane is changed. The air signals produced by these valves in turn operate hydraulic valves. The hydraulic valves control the flow of oil to the actuating cylinder (known as servos or hydraulic surface controls), which operate the control surfaces of the airplane. Power for operation of the types A-2 and A-3 automatic pilots is supplied by a vacuum pump and an oil pump, both of which are engine-driven.

b. In the following explanation of how the automatic pilot operates, control of motion of the airplane about the longitudinal axis will be considered. Control of motion about the vertical and lateral axes is accomplished similarly.

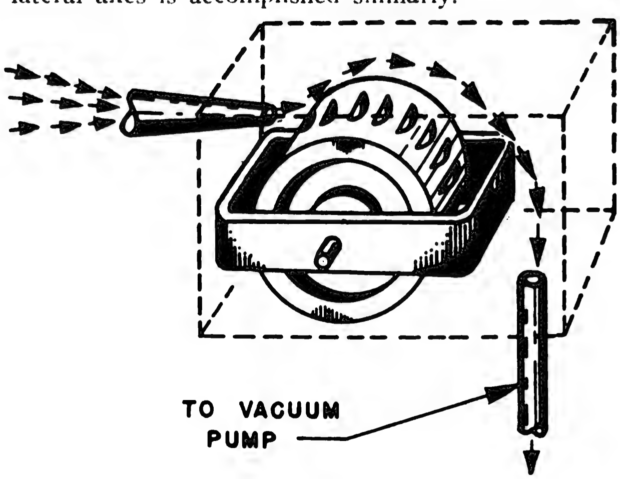


Figure 138. The gyroscope.

(1) The first step in operation is the removal of air by the vacuum pump from the cases of the two control boxes. Each box contains a gyroscope. A jet of air, allowed to enter each control box from the atmosphere, is directed against buckets cut into the outer edge of the rotor of the gyroscope, as shown in figure 138. The air causes the rotor to spin at a speed of approximately 12,000 rpm, thereby giving it the property of rigidity; that is, the

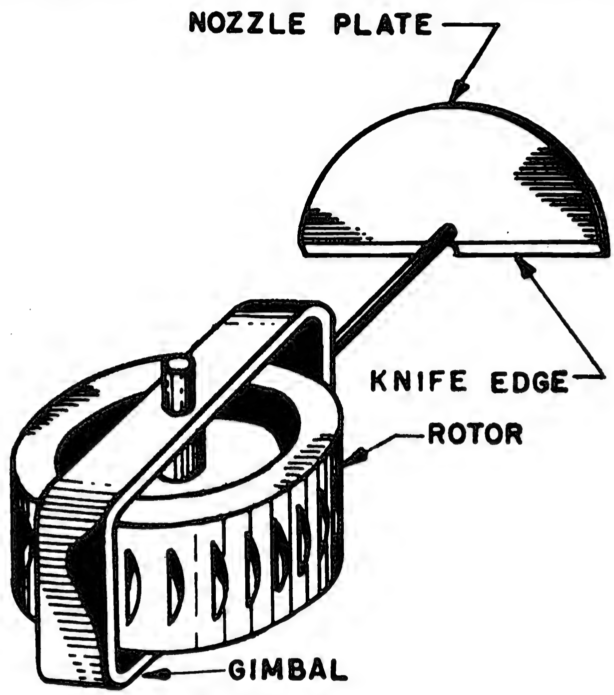


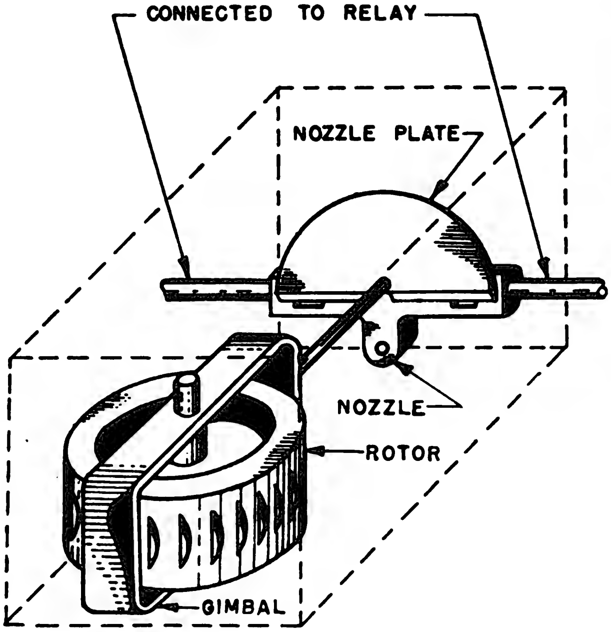
Figure 139. Gyroscope and nozzle plate.

tendency to maintain its position in space irrespective of the motion of the airplane about it.

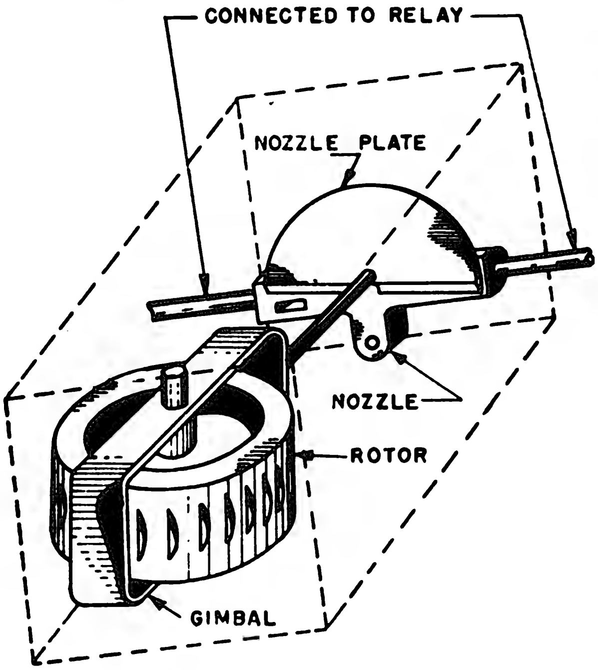
(2) Each gyro rotor is supported in the control box in a gimbal ring, which has a semicircular air-nozzle plate attached to it, as shown in figure 139. Since the gimbal ring is held in a fixed position because of the gyroscope's rigidity, the nozzle plate likewise remains rigidly in one position. In each control box jets of air are directed by an air nozzle, shown in figure 140①, against the knife edge of the nozzle plate. The amount of air allowed to flow from each air-nozzle opening is governed by its position in relation to that of the nozzle plate. When the airplane is in straight and level flight, the plate partially covers both nozzle slots and an equal amount of air enters through each, as shown in figure 140①. Each air nozzle is attached to the

gyro box and moves with the airplane, while the air-nozzle plate remains in position. The air nozzle and the air-nozzle plate constitute the air valve or "pick-off." When the airplane moves about the longitudinal axis, one of the nozzle slots is covered by the air-nozzle plate, while the other is opened, as shown in figure 140 ②.

(3) The two nozzle slots are connected, as shown



① *Neutral position.*



② *Displaced position.*

Figure 140. Gyro, air nozzle, and nozzle plate.

in figure 141, to chambers on opposite sides of a flexible diaphragm in the air relay. A very small

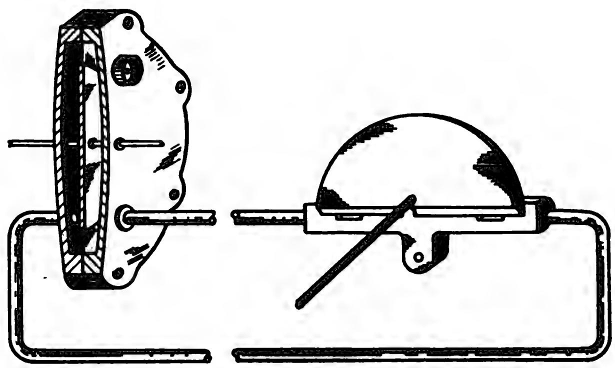


Figure 141. Air relay (neutral position).

hole (vent) in the housing of each of these chambers allows a metered amount of air to enter from the atmosphere.

(4) When the airplane departs from level flight, thus tilting the nozzle assembly in each gyro box and opening one of the air-nozzle slots, the increased rush of air through this slot causes greater suction to be applied to the side of the diaphragm connected to that slot. (See fig. 142.) At the same

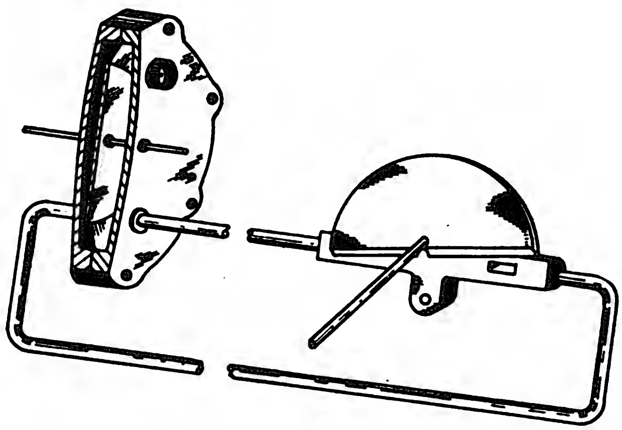
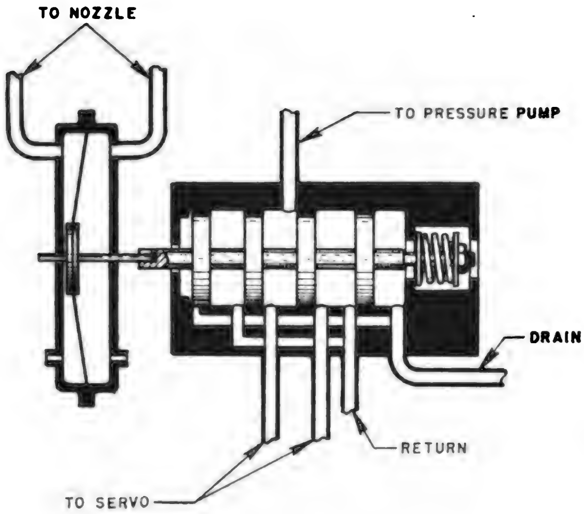


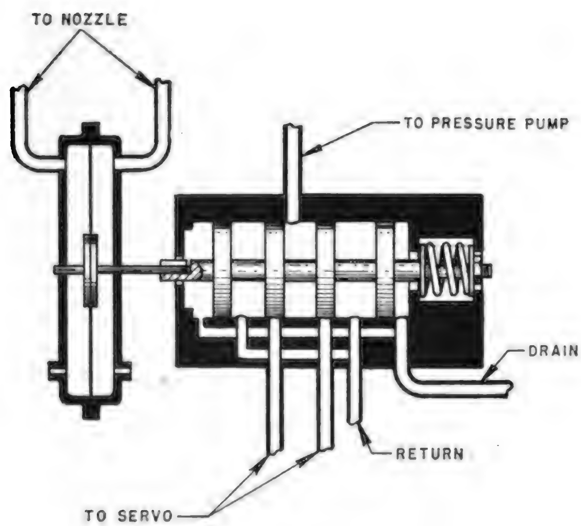
Figure 142. Air relay (displaced position).

instant, the other air-nozzle slot is closed and the suction is relieved on the other side of the diaphragm by the vent in the housing. It is this differential pressure which causes deflection, or movement, of the diaphragm. Movement of the diaphragm is now transmitted to the piston of the balanced oil valve, as shown in figure 143①, which directs the flow of oil to and from the actuating cylinder.

(5) When no air signal is applied to the diaphragm of the air relay, the balanced oil valve is held in the center of its travel by a spring at one end, as shown in figure 143②. But when the piston

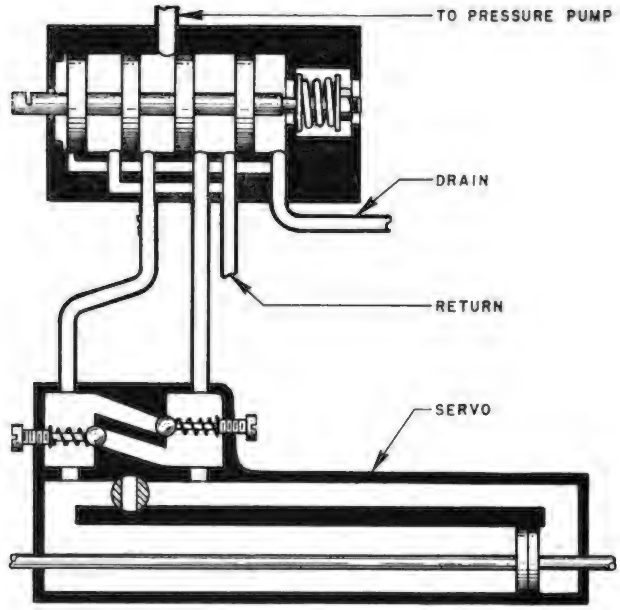


① *Displaced position.*

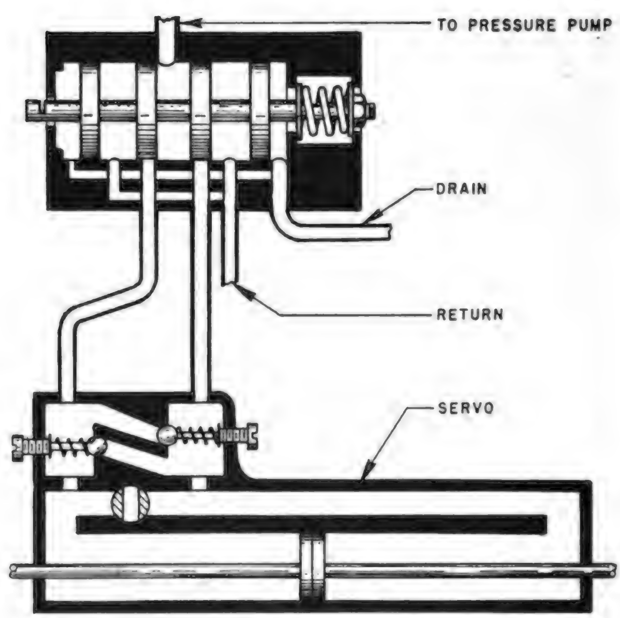


② *Neutral position.*

Figure 143. Diaphragm and balanced oil valve.



① *Neutral position.*



② *Displaced position.*

Figure 144. Balanced oil valve and servo-actuating cylinder.

moves in either direction from its neutral position, because of an air signal, shown in figure 144①, a port opens which allows oil under pressure to flow to one end of an actuating cylinder, as shown in figure 144②. The same movement of the piston of the balanced oil valve opens a port which allows oil to flow from the other end of the actuating cylinder of the oil reservoir, as shown in figure 145. Thus the piston of the actuating cylinder (one of those in the complete servo unit) is moved by the oil under pressure.

(6) The piston rod of the actuating cylinder is attached by means of cables to the ailerons. Movements of the piston rod, caused (as already explained) by movements of the diaphragm, thus cause corresponding movements of the ailerons. Control of the two ailerons in this manner keeps the lateral attitude of the airplane correct.

c. Follow-up System. In controlling an airplane it is necessary not only to apply control to bring the airplane back to normal flight, but also to begin to remove the applied control as the airplane is returning to level, so that the control surface will be back in neutral when the disturbance

of flight has been fully corrected. This adjustment is accomplished by the follow-up system.

(1) The air nozzles are not rigidly fastened to the cases of the control boxes, but are so mounted that they may be moved about the same axes as the nozzle plates. Movement of each servo piston is transmitted by means of the follow-up cable to its respective air nozzle, as shown in figure 146, thereby causing the air-nozzle slots to be rotated to meet the knife edge of the nozzle plate. Since only one follow-up cable is used for each control, a spring must be provided at the end of the cable to cause movement of the follow-up pulleys when the servo piston moves toward the follow-up cable.

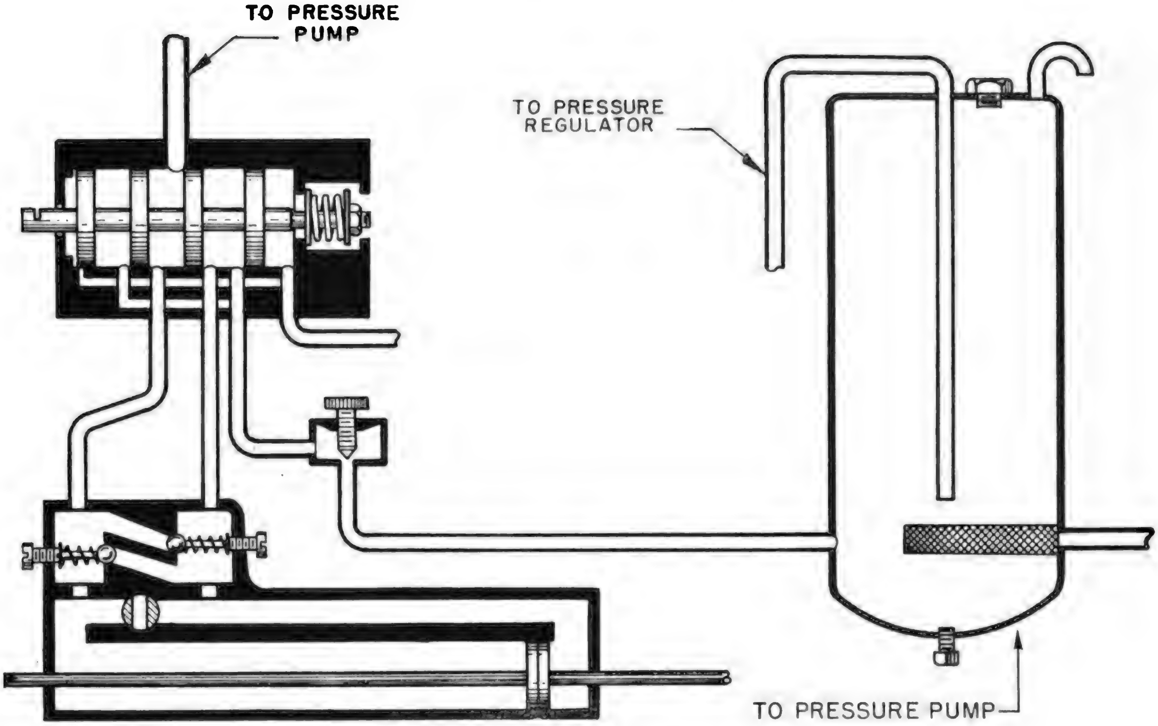


Figure 145. Balanced oil valve, servo, and sump.

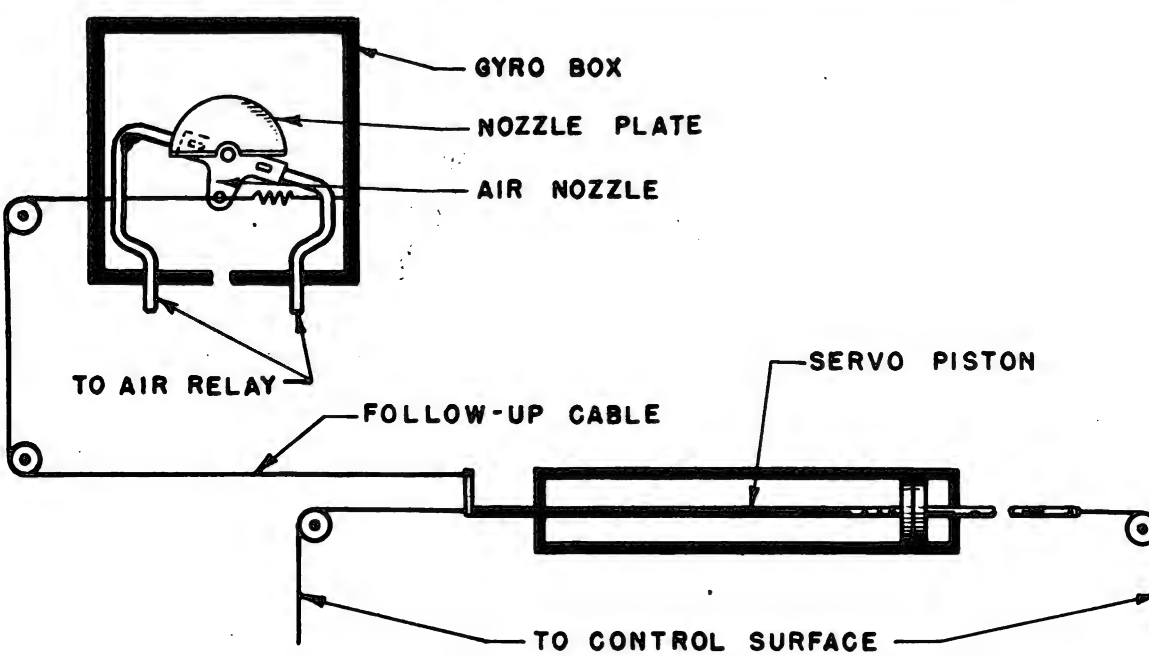


Figure 146. Follow-up system.

(2) Disconnect links (fig. 147) are placed in the follow-up cables near the servos. They consist of a plug and a snap which will pull apart at a predesignated load. If the follow-up cable should become fouled, the links will pull apart and free the airplane control system.

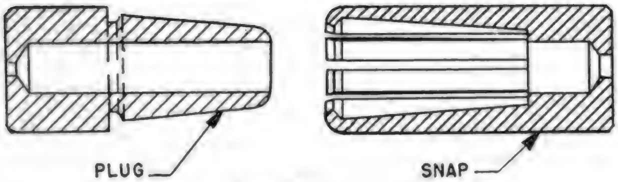


Figure 147. Disconnect links.

60. Description

a. The complete automatic pilot for an airplane consists of several items of precision equipment, some of which vary according to the requirements of various aircraft installations. A general description of each unit and its purpose follows.

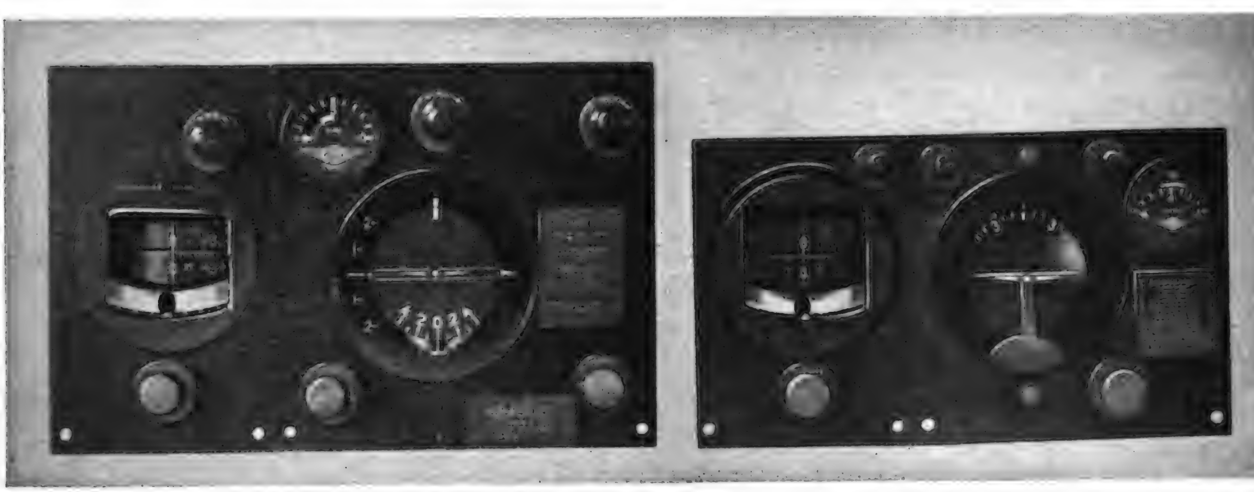
b. BANK-AND-CLIMB CONTROL BOX. In the bank-and-climb control box, there is one gyro assembly which is used for control and indication of motion about the lateral and longitudinal axes. The box also contains the air pick-offs (air valves) for these two controls. The front of the bank-and-climb box has an arrangement of indicators, graduations, and references very similar to that of the gyro horizon, so that in addition to controlling the airplane, the automatic pilot also serves to show the attitude of the airplane. These indications are provided even though the automatic pilot is disengaged.

(1) In addition to the indices of the simple gyro horizon, this unit also shows the direction and the amount of movement of the control surfaces and air pick-offs. Provision is made for caging the gyro by turning the caging knob. Manual control knobs are provided for both aileron and elevator control.

(2) A suction gauge is incorporated in the bank-and-climb box.

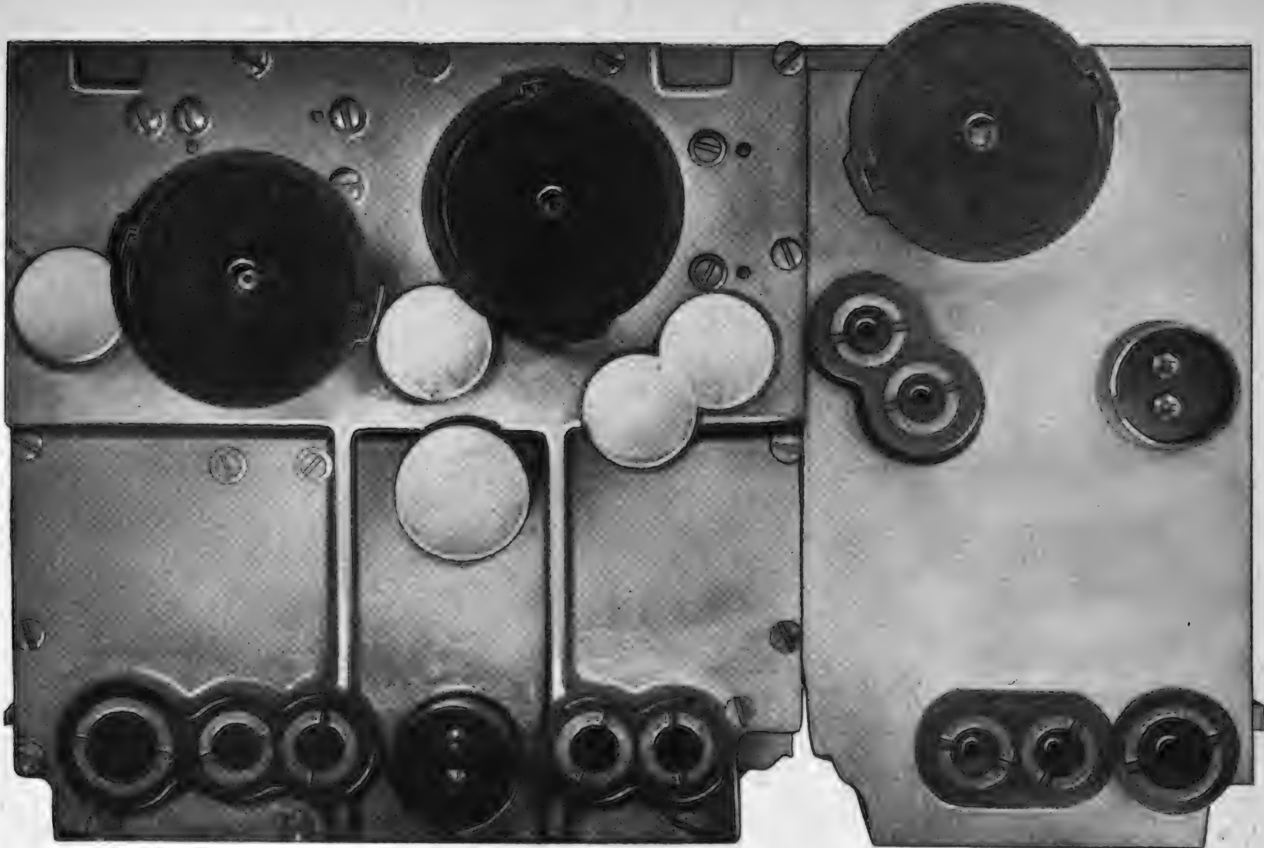
(3) In the type A-2 automatic pilot, the bank-and-climb box contains also a level-flight (constant-altitude) mechanism, but due to maintenance and operational difficulties, it has been discontinued entirely in the type A-3 pilot. Because of this and other minor changes in design, the control boxes of the type A-3 pilot are smaller and occupy considerably less panel space. A comparison of the types A-2 and A-3 bank-and-climb control boxes is shown in figures 148 and 149.

c. DIRECTIONAL-GYRO CONTROL BOX. In the directional-gyro control box there is a gyro which is the directional reference for both manual and automatic steering control. Attached to the vertical gimbal ring is a nozzle plate. An air nozzle is arranged with it. Visual indication of the heading of the airplane is shown by a card, also attached to the vertical gimbal. This card, together with a follow-up card fastened to the air nozzle, may be viewed from the front of the instrument so that the directional control box serves also a turn indicator. Provision is made for caging the gyro by pushing in on the caging knob. A manual control knob is provided to allow the heading of the airplane to be changed at will. A comparison of the types A-2 and A-3 directional gyro control boxes is shown in figures 148 and 149.

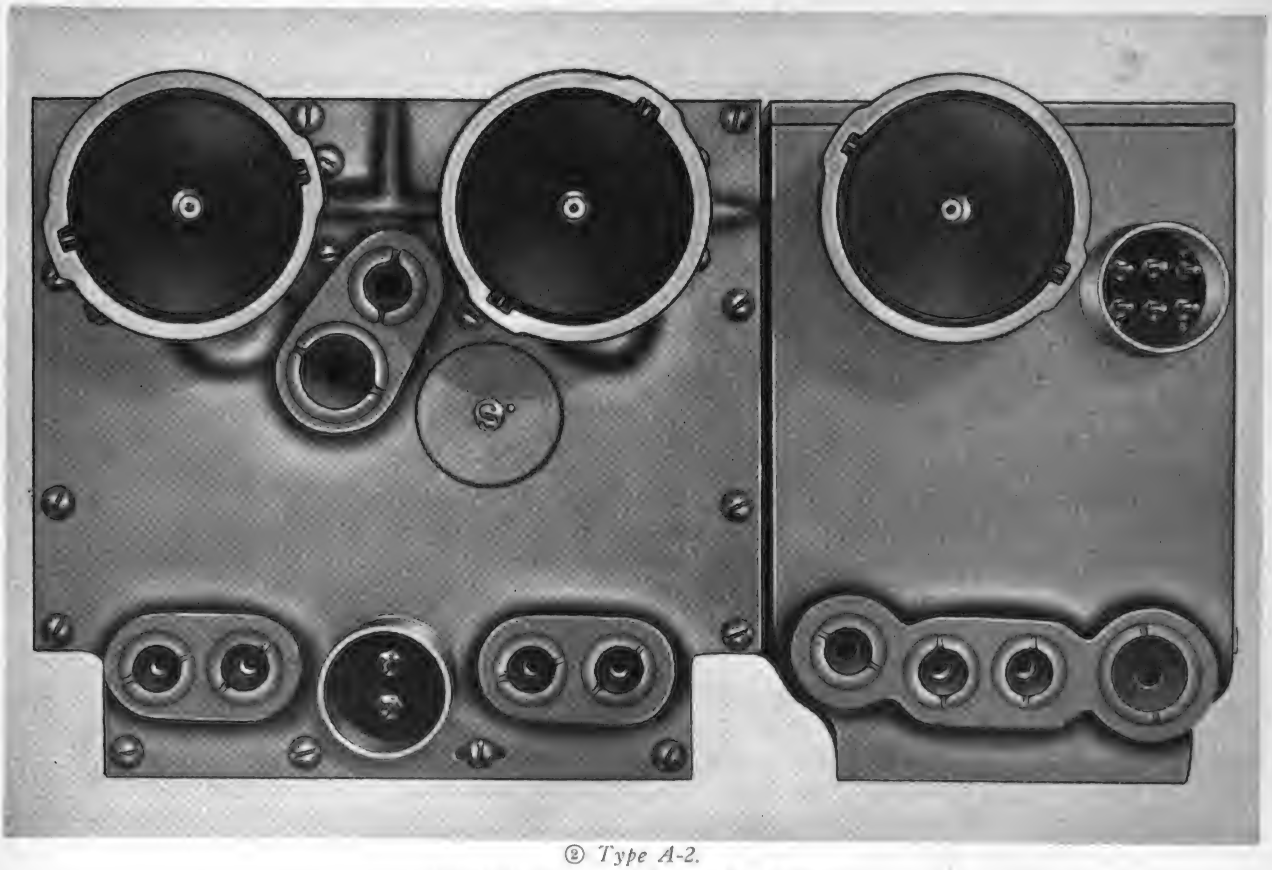


① *A-2 automatic pilot.* ② *A-3 automatic pilot.*

Figure 148. Control boxes—front view.

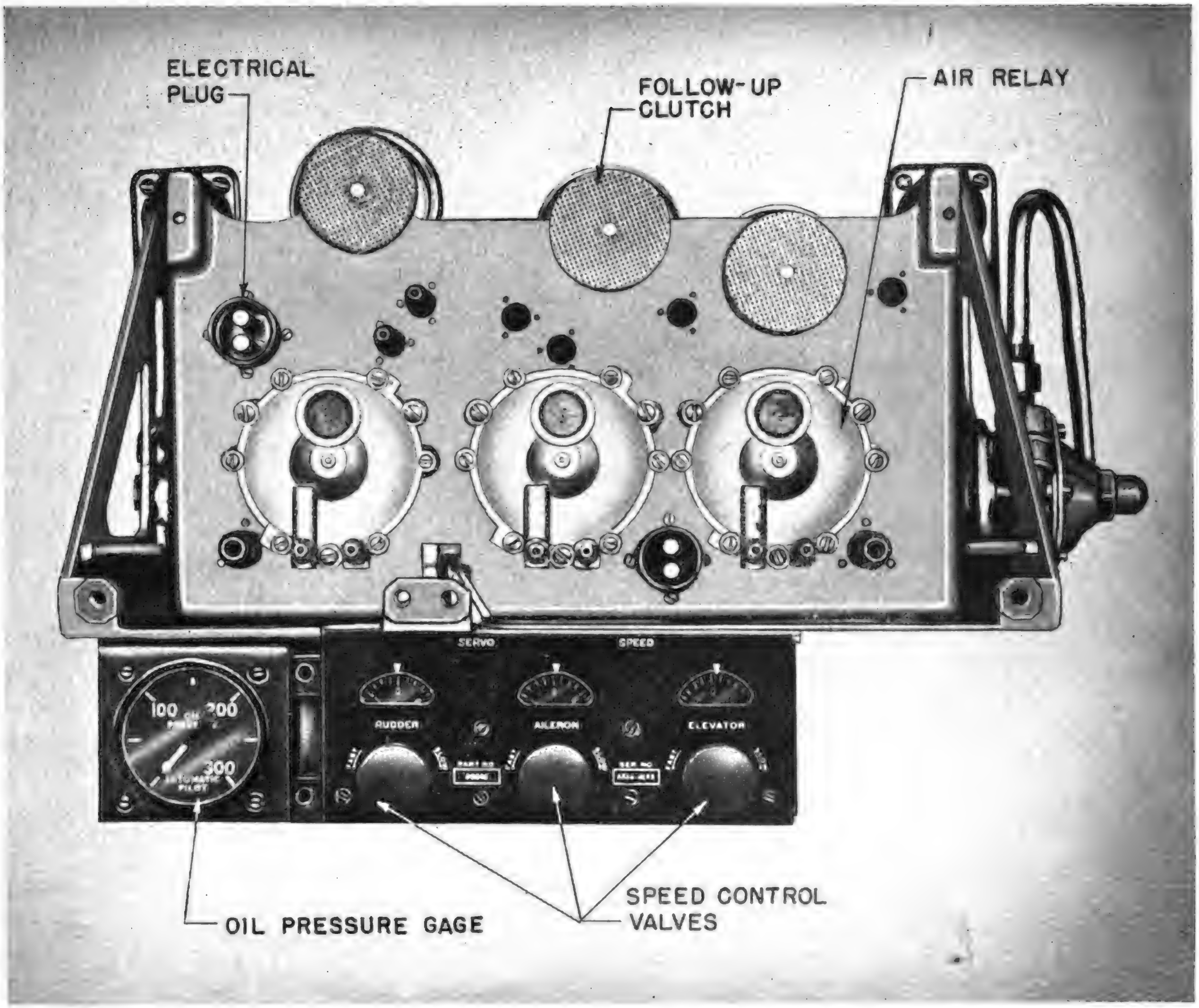


① *Type A-3.*



② *Type A-2.*

Figure 149. Control boxes—back view.

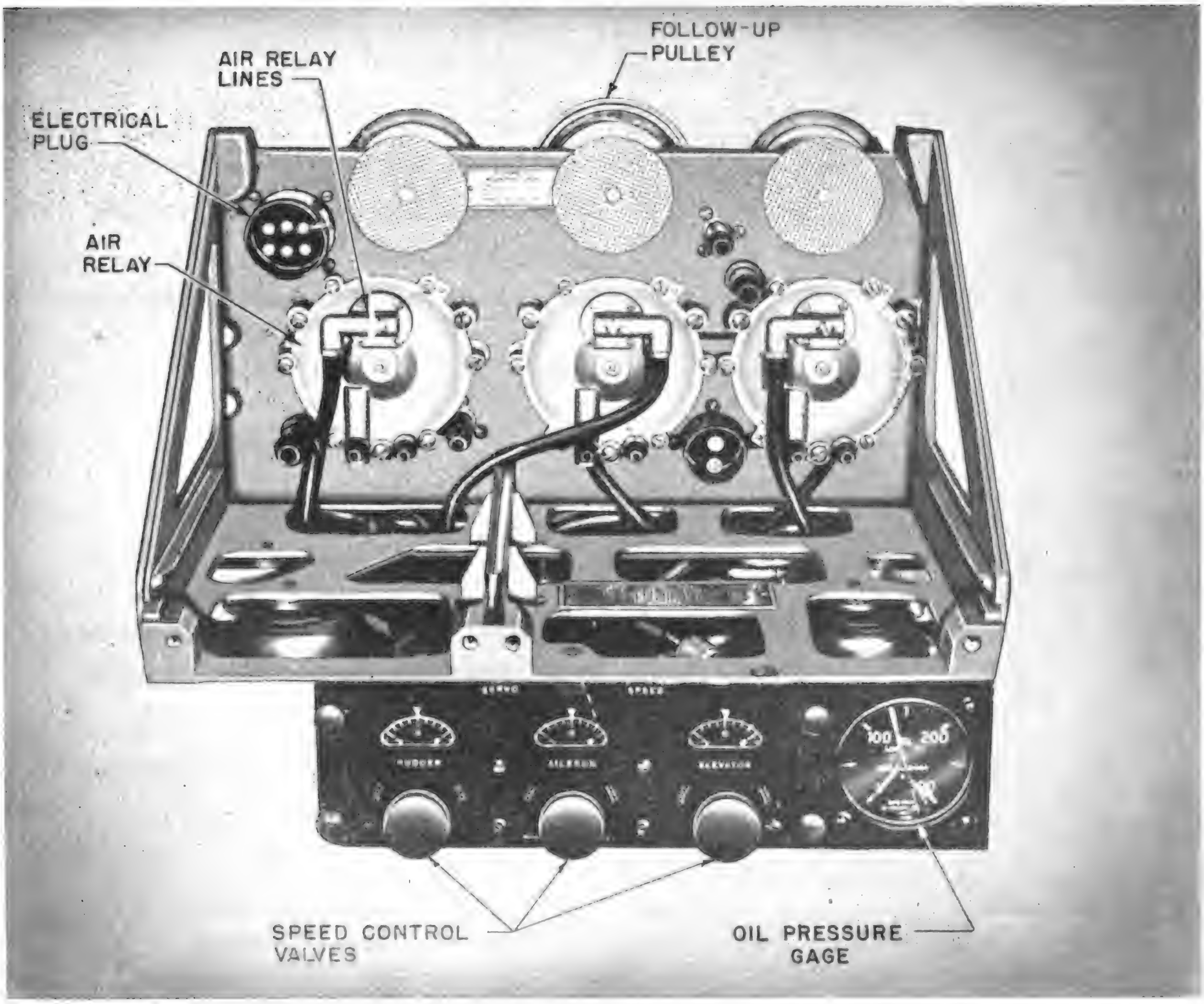


①
Figure 150. Mounting units.

d. MOUNTING UNIT. (1) A shock-mounted frame, to which air relays, balanced oil valves, follow-up pulleys, and oil-pressure and oil-drain manifolds are attached, makes up the mounting unit. (See fig. 150.) The unit is so constructed that the control boxes slide into place on tracks. Each is fastened with two cap screws. All electrical, mechanical, and air connections to the control boxes are made automatically when these boxes are secured in place. The three air relays with their balanced oil valves are fastened to the back of the mounting unit. Motion of the follow-up pulleys is transmitted to the follow-up system in the control boxes by cork-faced clutches, which are automatically engaged when the control boxes are secured in place. The pressure, exhaust, and drain manifolds on the under side of the mounting unit serve the three balanced oil valves through connecting tubing.

(2) The mounting unit is installed so that the fronts of the control boxes appear as parts of the instrument panel.

e. AIR FILTERS. Because of the very small clearances between the various parts and the absolute necessity for keeping frictional forces at a minimum, all air drawn into the system must be free of dust and other foreign matter. The type A-2 pilot has individual screened filters at each point of air intake. All air admitted into the type A-3 pilot is drawn in through a common filter and is supplied through a manifold to the various inlets. The common filter is located to receive the cleanest air possible. It is connected by means of tubing to the manifold on the mounting unit.



②
Figure 150—Continued.

f. Air Relays. Each air relay has two conical nipples which fit into rubber grommets in a control box when it is drawn into place. This arrangement automatically makes the air-signal connection between each air nozzle and its respective chamber in the air relay. The two chambers in the air relay are formed by two concave sides and the flexible diaphragm separating them. Each chamber of the air relay has a small calibrated vent which allows a metered amount of air to be admitted from the atmosphere. In the type A-2 pilot these openings are covered by filters, while in the A-3 a fitting is provided for a hose connection to the airfilter manifold. Deflection of the diaphragm is transmitted by a steel shaft to the core of the balanced oil valve.

g. Balanced Oil Valves. Each of the three balanced oil valves controls the applications of oil pressure to its respective actuating cylinder (servo unit). Oil under pressure is supplied to the center port of the balanced oil valve. (See fig. 144①.) Two ports are provided for connection to the ends of the servo unit, and two for the return of oil to the sump. The two return ports are interconnected, so that only one oil line returns to the sump. Since there is no packing at the ends of the balanced oil-valve core, some oil leaks past. The leakage is accumulated within the casting, and a connection is provided to drain it into the sump.

h. Servo Unit. The actuating cylinders of the servo unit actually operate the control surfaces of the airplane. The cylinders are connected to the control cables in such a manner that movements of the pistons, brought about by the application of pressure to one side and relief of pressure from the other, cause movements of the control surfaces. Incorporated in the servo unit are engaging valves

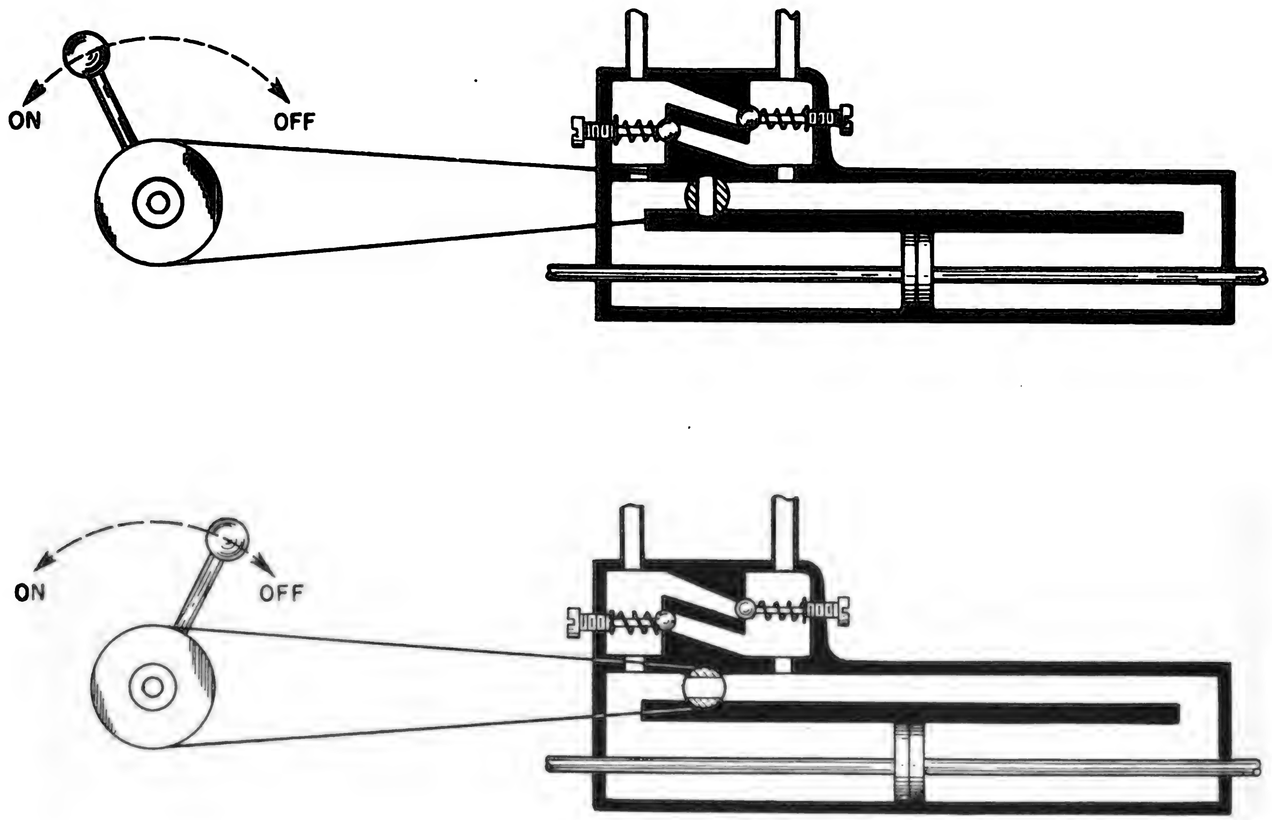


Figure 151. Engaging valves in ON and OFF positions.

(fig. 151) and overpowering relief valve, shown in the same illustration. The engaging valve serves to engage and disengage the automatic pilot. Opening of the valve allows free passage of oil from one end of the servo cylinder to the other, permitting the airplane to be controlled manually. The overpowering relief valves are means by which the human pilot may, without disengaging the automatic pilot, overpower it in an emergency. In the type of servo unit having two adjustments for each cylinder, the overpowering valves are of the spring-loaded ball type. (They are set at 75 to 100 percent of the operating pressure.) In the type of servo unit which has but one adjustment, the valve is of the piston type and should be adjusted to from 25 to 40 pounds per square inch over operating pressure.

(1) *Triple servo.* Of the servo units now in use, the triple servo is one of the three general types. All three actuating cylinders, together with their engaging valves and overpowering relief valves, are contained in the triple servo in one casting. The engaging valves may all be on one shaft. In appling this type of servo it is necessary that all three control cables be brought together, side by side, in some part of the airplane, since the servo piston rods replace sections of the cables.

(2) *Double-ended single servo.* In the double-ended single servo each cylinder with its engaging valve and overpowering valves is in a separate casting. Each servo may be mounted at the most convenient point for the application of that particular control. This is an advantage in many installations. However, the arrangement is such that all three engaging valves must be operated from the pilot's position by a single control.

(3) *Push-pull servo.* In the push-pull servo the cylinders are mounted separately and the piston rod extends from only one end. The other end of the cylinder is fixed to some structural member in the most advantageous position in the airplane. The piston rod is attached to a part of the control mechanism, such as the control column, as shown in figure 152. The engaging valve of this type of servo is hydraulically operated by the application or release of oil pressure (fig. 153.) Thus, all three cylinders are engaged or disengaged by a single "On-Off" valve at the hand of the pilot.

i. SPEED-CONTROL VALVES. The purpose of speed-control valves, one for each of the three

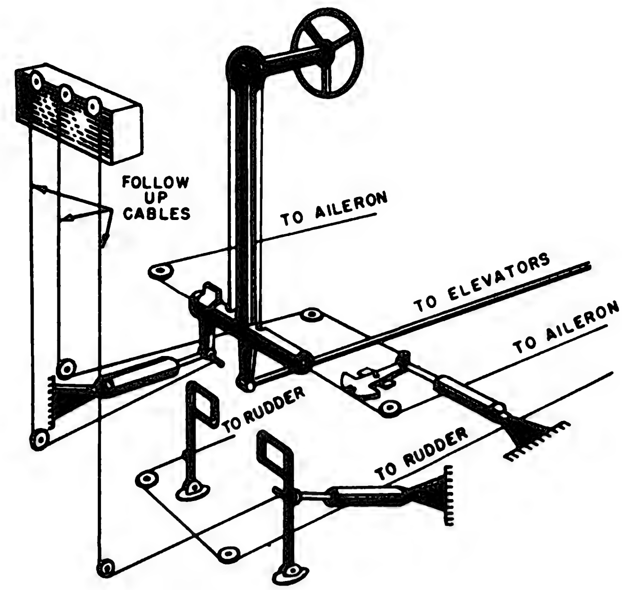


Figure 152. Typical servo installation.

controls, is to regulate the rate of flow of oil to the servo units and thus the speed of corrective movement of the control surfaces. (See fig. 154.) The number of turns that the valves are open is

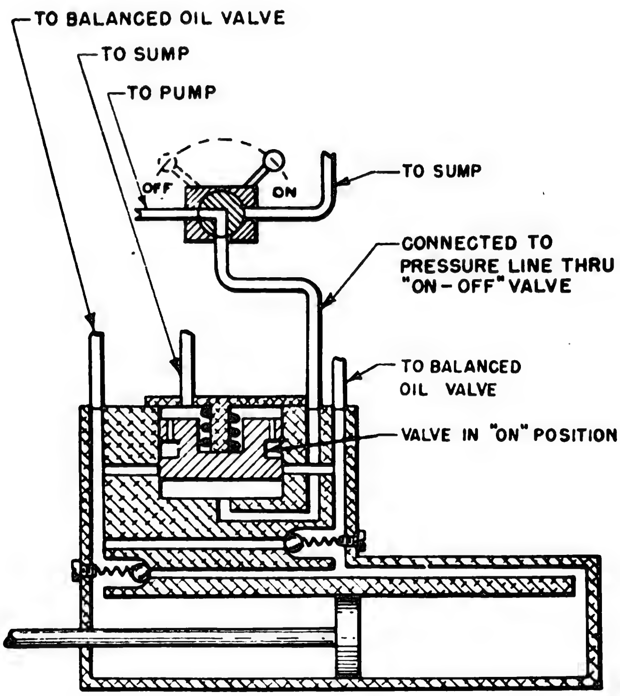


Figure 153. Push-pull servo.

shown by a dial directly above the knob. The proper amount that the valves should be open varies with different airplanes and with flight conditions. In flight the valves should be opened as much as pos-

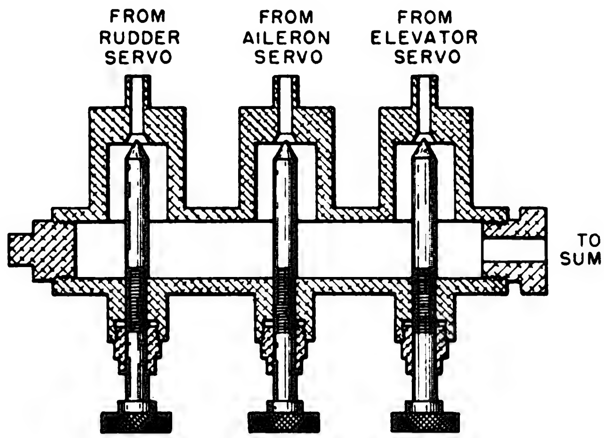


Figure 154. Speed-control valves.

sible, with best control characteristics still being retained. In the type A-2 pilot speed-control valves are placed in the lines supplying oil to the balanced oil valves. In the type A-3 pilot they are in the oil return line leading from the balanced oil valves back to the sump. A further improvement in design of the speed-control valves in the type A-3 pilot provides a more substantially constant rate of movement of the servo piston for any setting regardless of the pressure. This new type of valve assembly is being installed in the return line on the type A-2 pilots during major overhaul.

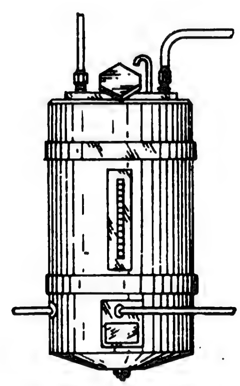


Figure 155. Reservoir or sump.

j. Oil Sump. The function of the oil sump is to serve as a reservoir for the oil of the hydraulic system. It has a capacity of about 1½ gallons. A sight gauge is provided to show the oil level, as indicated in figure 155. A strainer in the base of the sump removes larger particles of foreign matter from all oil drawn from the sump.

k. Oil-pressure regulator. A spring-loaded bypass valve (fig. 156) is used in all automatic pilot installations. This valve automatically regulates the oil pressure from the pump and permits the

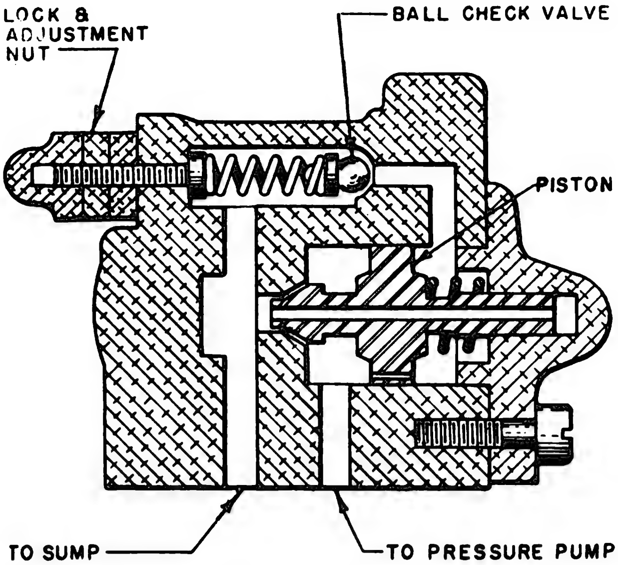


Figure 156. Oil-pressure regulator.

oil to circulate back to the sump whenever the balanced oil valve cuts off the circulation to the servo unit. The pressure regulator may be adjusted to the correct pressure for the particular airplane in which it is installed.

l. OIL PUMP. The engine-driven oil pump provides the necessary pressure and flow of oil for operation of the automatic pilot when the engine is in operation. The oil filter (fig. 157) on the pressure side of the oil pump, provides a means of maintaining a flow of clean oil through the hydraulic system. The filter element can be withdrawn for cleaning without disconnecting any piping or fittings. Clean oil is absolutely necessary because of the close clearances of the balanced oil valve. A very small particle of grit may destroy the freedom of movement of the core and thus prevent proper operation of the balanced oil valve.

m. BYPASS VALVE. A bypass valve is incorporated in the A-2 automatic pilot for use in case of an emergency, such as a serious leak in the system. It directs oil back to the sump without the oil passing through the balanced oil valve. (See fig. 158). The bypass valve is safetied in the "On" position and cannot be used to disengage the pilot. When the valve is in the "On" position, the oil output of the pump is permitted to circulate through the main system. On the A-3 pilot, this valve is called the "master control valve" and is used to engage and disengage the pilot. When the valve is in the "On" position, the oil is directed to the system to operate the servo piston. The "Off" position directs oil back to the sump so that the output

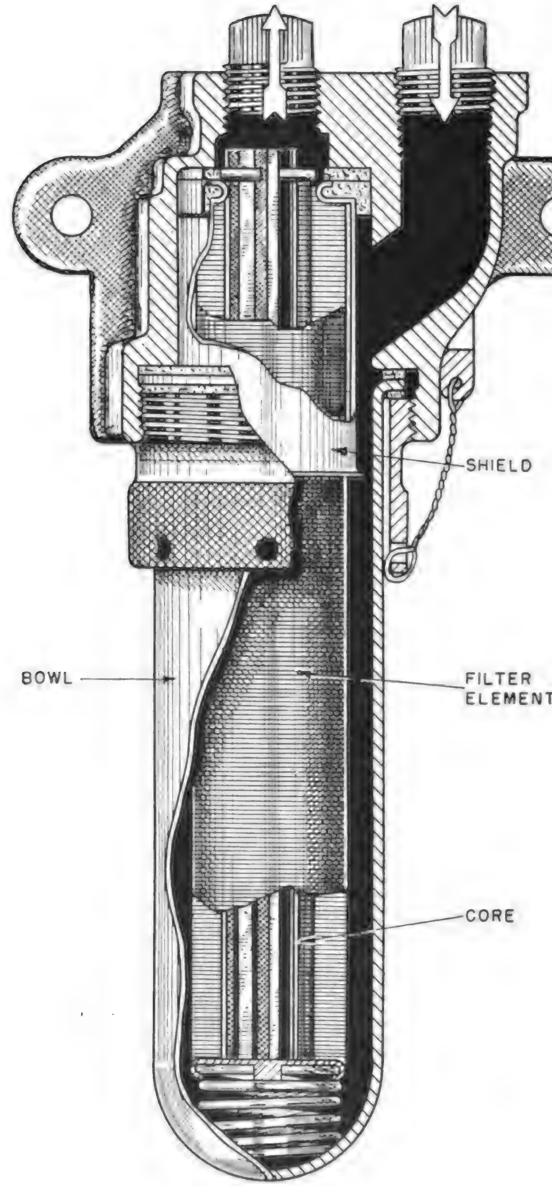


Figure 157. Oil filter.

of the oil pump cannot circulate through the main system.

n. OIL-PRESSURE GAUGES. The pressure being supplied to the balanced oil valve is indicated by an oil-pressure gauge connected to the pressure-manifold block and mounted directly below the control units. This is a conventional Bourdon-tube pressure gauge with a range of 0 to 300 pounds per square inch. The desired operating pressure will vary with different types of airplanes.

o. DRAIN TRAP. In installations where the balanced oil valve is not high enough to permit the leakage from the balanced oil valve to flow to the sump by gravity, a drain trap, shown in figure 159,

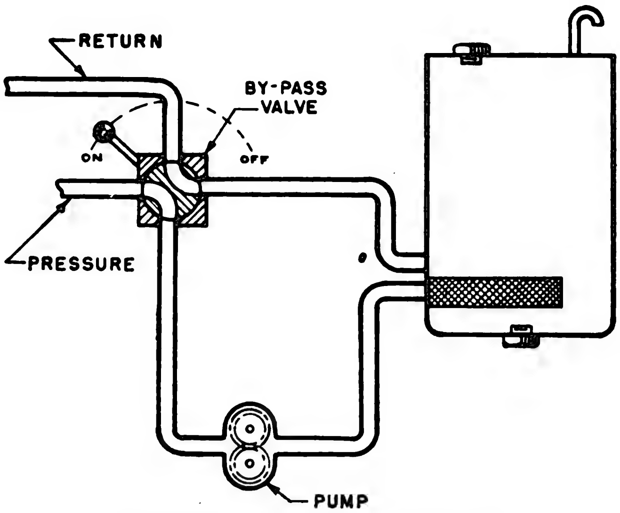


Figure 158. Bypass valve installation.

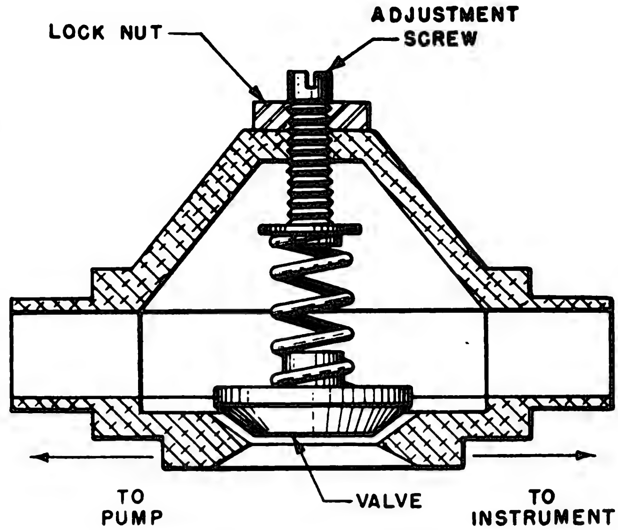


Figure 160. Vacuum relief valve.

is necessary. The drain trap contains a float which operates a valve connecting the trap to lift the float. Before all the oil is pumped out of the trap, the float lowers and closes the valve, thus preventing air from entering the pump lines.

p. VACUUM PUMP. Suction for driving the gyros and operating the air pick-offs and air relays is supplied by an engine-driven vacuum pump.

q. VACUUM-RELIEF VALVE. An adjustable vacu-

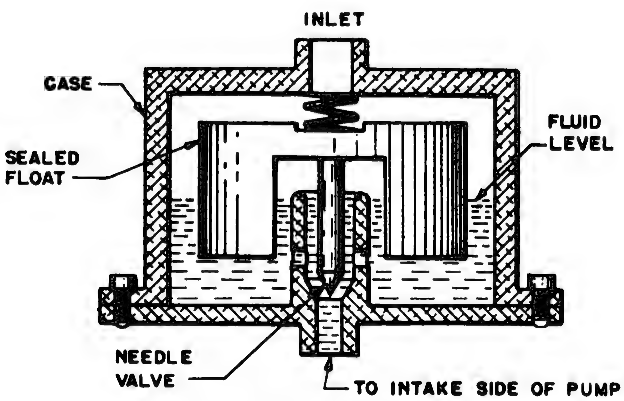


Figure 159. Drain trap.

um-relief valve (fig. 160) is used to maintain the vacuum supply at the amount best suited to automatic-pilot operation. If the suction becomes too high, the spring-loaded disk rises from its seat and admits air to relieve the suction to the adjusted valve.

61. Operation

a. Only aileron control will be used here to illustrate the operation of the automatic pilot. The rudder and elevator controls operate in a similar manner.

b. Assume that the airplane has been displaced about the longitudinal axis so that the right wing is lower than the left. The gyro maintains its vertical axis, holding the knife edge of the nozzle plate in a horizontal position, as shown in figure 161. With the pick-off in this position, slot *A* will be open, allowing suction to be applied to the left side of the diaphragm of the air relay. Since slot A^1 is closed, atmospheric pressure is applied to the right side of the diaphragm. This pressure causes the diaphragm to be deflected to the left, moving with it the core of the balanced oil valve. Oil is allowed to flow from the pressure supply to the left side of the actuating cylinder. Since the same movement of the balanced oil valve opens the return port, oil is allowed to flow back to the sump from the right side of the servo unit and the piston moves to the right, thereby applying the necessary aileron control to restore the aircraft laterally to level flight.

c. The movement of the servo piston to the right causes, through the follow-up system, rotation of the air nozzle to the left against the pull of the balance spring. This rotation moves slot A^1 down and slot A up. When these ports reach a neutral position, both valves open, the air relay, and the balanced oil valve are centered. Movement of the servo piston then stops in an extended position as the airplane continues moving toward its normal attitude. Rotation of the air nozzle to the left beyond the neutral point begins the cause movement of the servo piston to the left. The ratio of movement of the servo piston to that of the air nozzle is such that the controls arrive at neutral simultaneously.

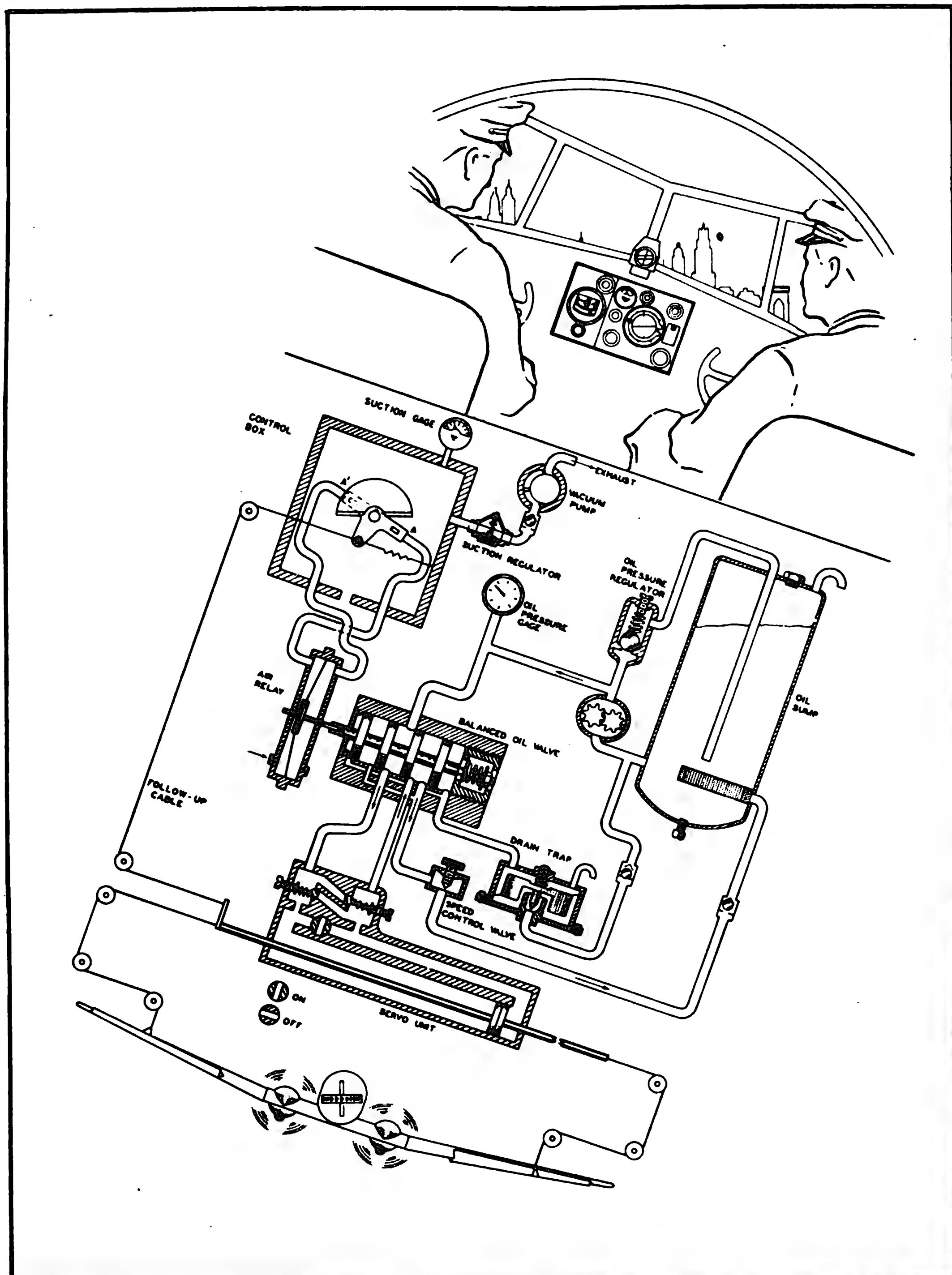


Figure 161. A-2 and A-3 automatic pilot.

62. Installation

Initial installations of the automatic pilot are made at the airplane factories or at major repair depots. Removal or replacement of major units should be accomplished in the service by qualified instrument personnel only.

63. Inspection and Maintenance

a. Schedule of Inspections. Following is a schedule for inspections:

(1) *Preflight.* Ground-test automatic pilot during engine warm-up in accordance with applicable Technical Order.

(2) *Daily.* Inspect lighting system of type A-2 pilot for proper operation.

(3) *Every 50 hours.* Inspect filter element in oil filter and air filter for cleanliness. Inspect control units and accessories for security of mounting. Inspect control units for broken or loose cover glass. Check control units for discolored or chipped luminous markings. Examine shock absorbers for sign of failure. Inspect the follow-up system—the pulleys for freedom of operation, alignment, and anchorage and the cables for tension, broken wires, and safetied turnbuckles. Check all piping and fittings, including flexible hose and hydraulic and vacuum-system lines, for leaks. Inspect all air screens and clean any that show dirt.

(4) *Every 100 hours.* Lubricate follow-up pulley springs and bearings with gyro instrument grease.

(5) Engine change or every 300 hours, whichever comes earlier. Remove gyro control units for bench test and replace rubber grommets.

b. PREFLIGHT INSPECTION. The following procedure and order of execution will be carried out during each preflight inspection of the airplane.

(1) Check for sufficient amount of oil in sump. It should be three-fourths full. Only mineral-base hydraulic oil is used.

(2) Turn "On-Off" valve to "Off" position.

(3) Start engine.

(4) Check vacuum on suction gauge. It should be not less than 3.75 or more than 4.25 inches of mercury.

(5) Check oil pressure on oil gauge. Be sure the speed control valves are closed. The oil pressure should be within 10 percent of the recommended operation pressure.

(6) Open speed-control valves at least four turns.

(7) Uncage bank-and-climb gyro.

(8) Set and uncage directional gyro.

(9) Centralize all controls.

(10) Turn course-setting knob until upper or reference card coincides with directional card.

(11) Turn aileron and elevator trim knobs to bring the pointers on their respective index markers to zero.

(12) Engage automatic pilot.

(13) Rotate all three control knobs and observe operation of automatic pilot.

(14) Check for air in system. Apply manual pressure to each control in each direction. Any resiliency (springing back) in the controls indicates air in the hydraulic system. The resiliency is due to the compression of the air as force is applied, and expansion as the force is removed.

(15) Check to be sure automatic pilot can be overpowered with on-off valve in "On" position.

c. REMOVAL OF AIR FROM SYSTEM. The following procedure is recommended for removal of air from the system during each preflight inspection. It serves both as a check of operation and as a precaution against undetected air in the system.

(1) Turn all control knobs until index markers remain separated.

(2) Disengage pilot and hold controls in this position for a few seconds.

(3) Reengage pilot and repeat operations (1) and (2) in the opposite direction.

d. EXAMINATION OF AIR FILTERS. All air filters on the type A-2 automatic pilot are inspected every 50 hours, or oftener if necessary, and any that show dirt accumulation are cleaned in Varsol, carbon tetrachloride, or some similar solvent. The frequency of cleaning air filters varies widely with service conditions. Operation under dusty conditions often necessitates more frequent servicing. There is one screen in the directional-gyro control box, one in the bank-and-climb gyro control box, two in each air relay on the mount assembly, and one in each of the two suction regulators.

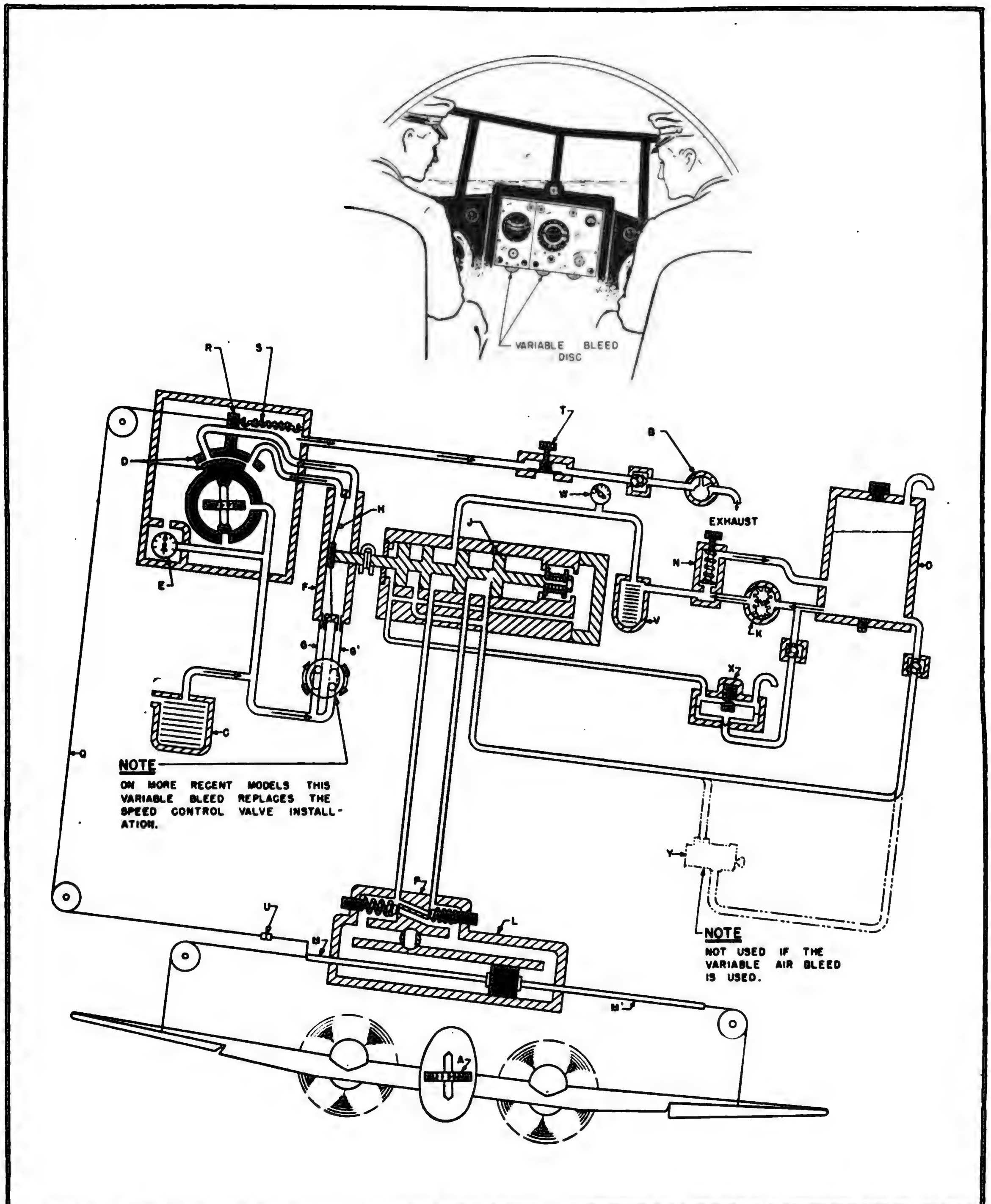
e. CLEANING COMMON AIR FILTER. The filter element of the common air filter in the type A-3 automatic pilot is inspected for cleanliness every 50 hours. To clean the air-filter element, remove the filter from the housing, plug one end, and apply low-pressure air to the other end. With low pressure still applied to the inside, blow the dirt away from the outside surface of the element with a high-pressure air line. The filter element may be cleaned by soaking in Varsol, carbon tetrachloride, or some other approved solvent for 10 to 15 minutes. The filter element is then thoroughly dried by application of low-pressure air.

f. CLEANING CLOTH BOOT. A cloth boot is installed around the element of the oil filter at the time of installation of the automatic pilot. The boot is inspected for cleanliness after every 25 hours of operation. It is washed in a suitable solvent and dried, and a new boot of airplane fabric is installed. The use of the cloth boot may be discontinued when no further deposits are found.

g. REMEDY FOR SLUGGISH OPERATION AT LOW TEMPERATURES. Sluggish operation of the automatic pilot at extremely low temperatures may be

remedied by disengaging the unit and turning the control knobs so as to offset the index markers by a few degrees. Warm oil from the pump will then flow through the servo lines and return the automatic pilot to normal operation.

h. Handling of Control Boxes. When removing or replacing the control boxes, the two capscrews should be run in or out evenly, so as to prevent damage to the rudder grommets in the rear of the boxes.



A. Gyro rotor.	*F. Air relay.*	*L. Hydraulic surface control.*	*Q. Follow-up cable.*	*V. Hydraulic filter.*
B. Vacuum pump.	*G-G¹. Ports.*	*M-M¹. Piston rod.*	*R. Follow-up lever.*	*W. Oil pressure gauge.*
C. Air filter.	*H. Diaphragm.*	*N. Pressure regulator.*	*S. Balance spring.*	*X. Drain trap.*
D. Pick-up assembly.	*J. Balanced oil valve.*	*O. Sump.*	*T. Suction regulator.*	*Y. Speed-control valve.*
E. Diaphragm.	*K. Hydraulic pump.*	*P. Overflow valve.*	*U. Disconnect link.*	*Z. Bypass valve.*

Figure 162. A-3A automatic pilot—schematic drawing.

64. A-3A Automatic Pilot

a. GENERAL. A schematic drawing of this autopilot is shown in figure 162. It will be noted that the principal difference between the type A-3A and the type A-3, shown in figure 161, is the type pick-off used. Instead of the in-line pick-off shown in figure 140, this pilot has a radial pick-off which is shown schematically in figure 162. The principal advantage of this pick-off is that its signals are not affected by temperature changes.

b. SPEED CONTROL VALVES. Older A-3A pilots have fixed air relay bleeds and therefore incorporates three speed control valves. Their purpose is explained in paragraph 59*h*. The panel on which they are mounted is mounted on or near the mount assembly and readily accessible to the pilot and copilot.

c. ADJUSTABLE AIR BLEEDS. Later model A-3A pilots do not have speed control valves. The desired sensitivity and speed of response is obtained by use of adjustable air bleeds. By means of these units the size of the bleeds to the air relay is varied. The controls for these bleeds is located on the bottom of the autopilot control panel. (See fig. 163.) Opening the bleeds increases sensitivity. Closing the bleeds for any air relay shuts-off the control to which that air relay applies.

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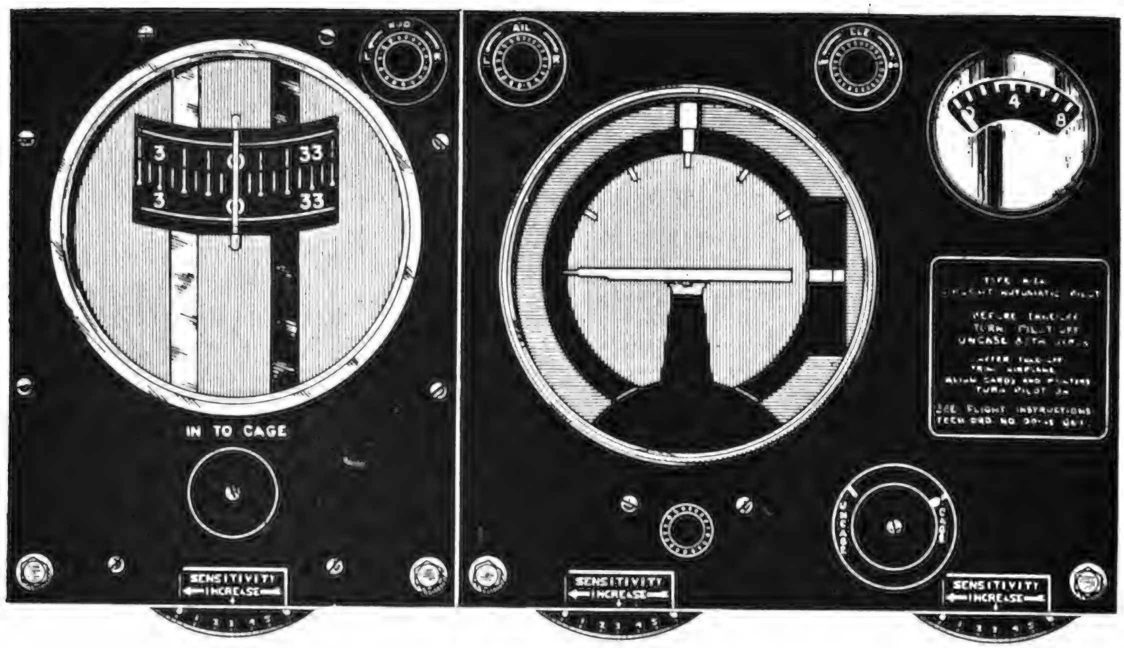
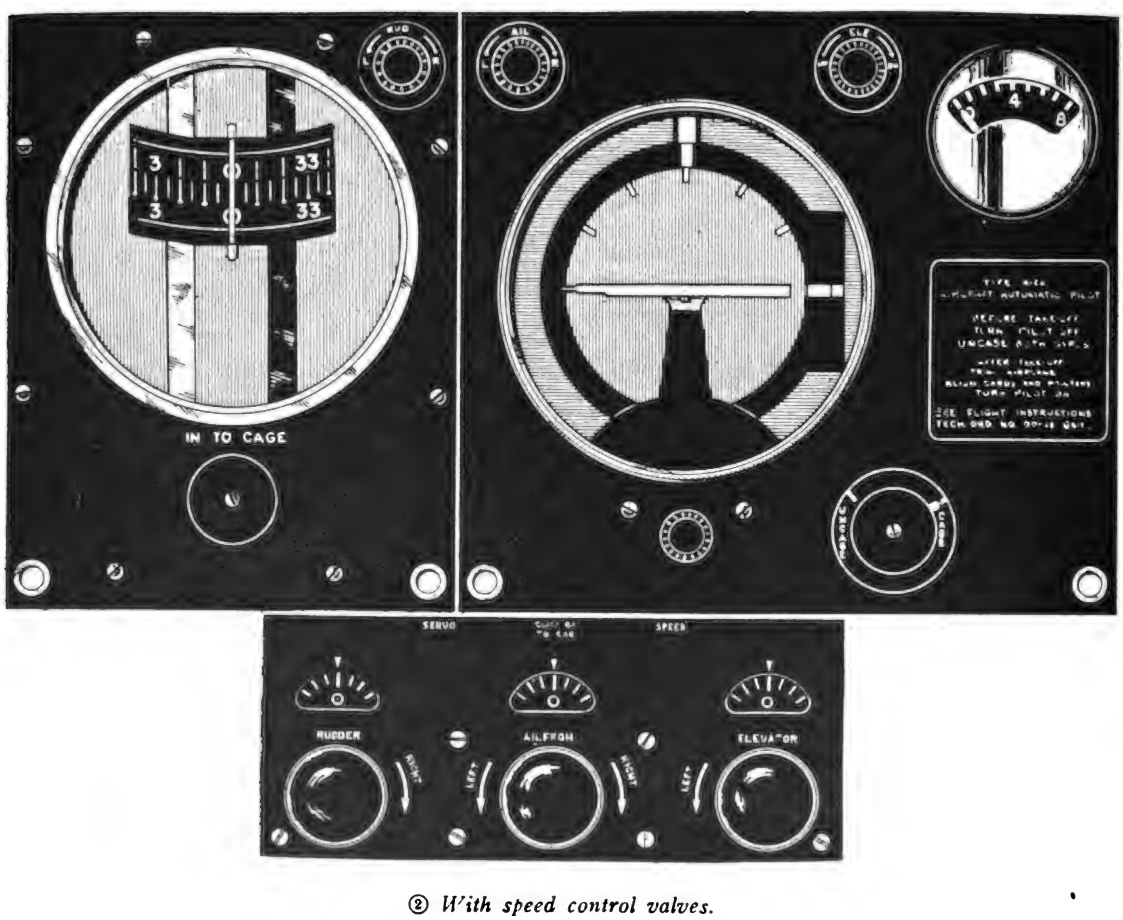


① *With variable air bleed dials.*



② *With speed control valves.*

Figure 163. A-3A automatic pilot (front view).

Trouble	Possible cause	Remedy
1. Insufficient vacuum (less than 3 in. Hg).	*a.* Suction regulator improperly adjusted.	*a.* Adjust regulator valve.
	b. Pump failure.	*b.* Repair or replace pump.
	c. Leak or break in vacuum line.	*c.* Locate and repair.
	d. Incorrect gauge reading.	*d.* Check gauge for calibration; repair or replace.
2. Excessive vacuum (over 5 in. Hg).	*a.* Suction-regulator improperly adjusted.	*a.* Adjust regulator valve.
	b. Air-intake filter clogged.	*b.* Replace filter element.
		c. Repair or replace regulator.
		d. Check gauge for calibration; repair or replace.
3. Insufficient oil pressure.	*a.* Low oil supply.	*a.* Refill oil tank.
	b. Leak or break in oil line.	*b.* Locate and repair.
	c. Pressure regulator not properly adjusted.	*c.* Adjust with speed-control valves closed. Remove cap of regulator and loosen lock nut. Screw in to raise pressure; screw out to lower pressure.
	d. Pressure regulator dirty or defective.	*d.* Clean or repair and readjust.
	e. Pump intake line or filter clogged.	*e.* Check or repair and readjust.
	f. Defective oil pump.	*f.* Repair or replace pump.
	g. Automatic-pilot oil-pressure valve in "Off" position.	*g.* Turn valve to "On" position.
	h. Incorrect gauge reading.	*h.* Check gauge for calibration; repair or replace.
4. Excessive oil pressure.	*a.* Pressure regulator not properly adjusted.	*a.* See 3*c* above.
	b. Pressure regulator stuck in closed position.	*b.* Free, clean, and readjust.
	c. Incorrect gauge reading.	*c.* Check gauge for calibration; repair or replace.
5. Foaming of oil.	*a.* Leak in needle valve of drain trap.	*a.* Replace drain trap.
	b. Air leak in line from sump or oil reservoir to oil pump inlet, or leak in pump.	*b.* Locate and repair.
6. No control.	*a.* Master control lever "Off."	*a.* Place lever in "On" position.
	b. Insufficient vacuum.	*b.* See 1 above.
	c. Insufficient oil pressure.	*c.* See 3 above.
	d. Speed-control valves closed.	*d.* Open speed-control valves.
7. Control in one direction only.	*a.* Air leak at air-pick-off (air nozzle) grommet between control unit and mount assembly.	*a.* Replace grommet.
	b. One air-relay screen clogged.	*b.* Remove and clean with suitable solvent.
8. Air continuously in system.	Leak in intake side of oil pump.	Replace lines or tighten fittings.
9. Controls oscillating or hunting.	*a.* Air in oil system.	*a.* Remove air.
	b. Caged gyros.	*b.* Uncage gyros.
	c. Speed-control valve setting too high.	*c.* Decrease setting of valve.
10. Control lagging in both directions.	*a.* Both air-relay screens dirty.	*a.* Clean screens.
	b. Low suction.	*b.* Increase suction.
	c. Low oil pressure.	*c.* Increase pressure.
	d. Leaking grommets.	*d.* Replace grommets.

SECTION XIII
A-5 AUTOMATIC PILOT

65. Purpose and Use

The type A-5 automatic pilot is used primarily to maintain automatically the desired heading and attitude on long flights and to furnish the accurate control which is necessary when it is used in conjunction with aircraft armament equipment. The type A-5 pilot permits the airplane to be controlled electrically from a position other than the pilot's and co-pilot's position and thereby eliminates the necessity for oral communication between the bombardier and the human pilot.

66. Principle of Operation

The reference for control is supplied by the rigidity of two electrically driven gyroscopes. One is mounted with its axis of rotation horizontal (fig. 164) as in the turn indicator, so as to furnish reference for rudder control. The other gyro, in figure 165, spins about a vertical axis and furnishes reference for aileron and elevator control. Any deviation in attitude or heading of the airplane from the reference maintained by the gyroscopes creates an electrical signal by displacing an electrical pick-off (fig. 166) with respect to an iron shoe. The alternating-current signals thus created are amplified and are employed to control two oil valves. (See fig. 167.) The oil valves control the application of pressure to each of the servo pistons. If the respective pressures applied to the pistons are unequal, a movement results which is transmitted to a cable drum through a gear and rack. (See fig. 168.) Proper corrective control is transferred from the servo drum to the control surface by control cables.

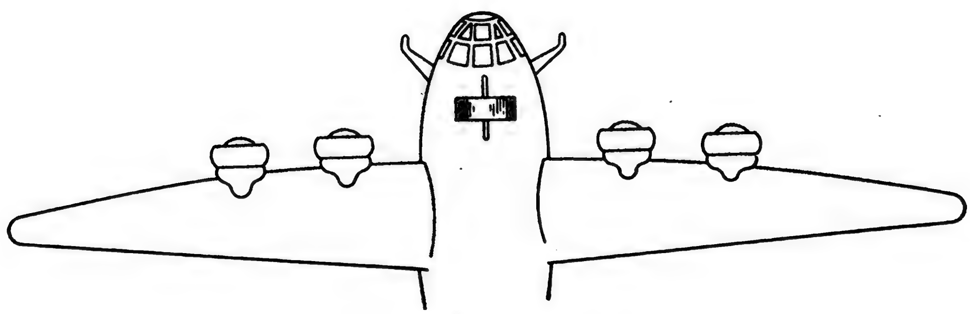


Figure 164. Rudder-control gyro.

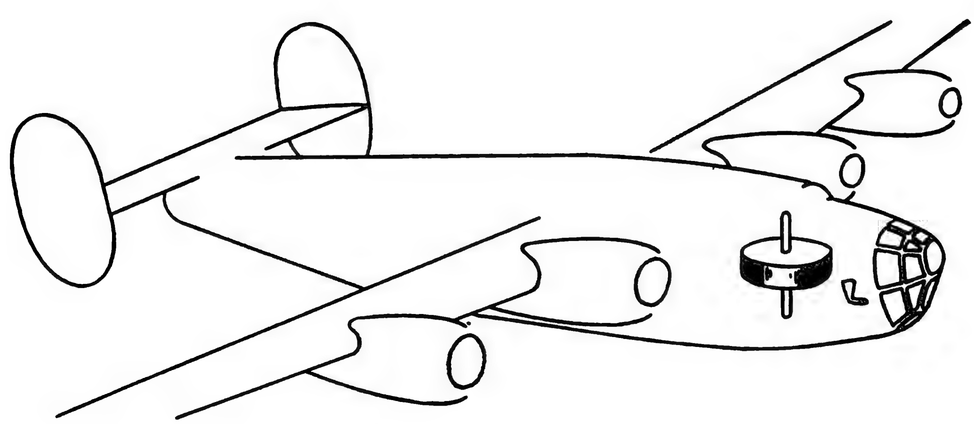


Figure 165. Aileron-and-elevator control gyro.

67. Description

a. The complete automatic pilot is made up of:

(1) A control unit.

(2) A vertical-gyro unit.

(3) A directional-gyro unit.

(4) An amplifier rack.

(5) Three main servo units for aileron, elevator, and rudder.

(6) A pilot director indicator (P.D.I.).

(7) Turn control.

b. The control unit (fig. 169) is mounted near the hand of the pilot and provides complete control of the airplane from his station. Three indicators *A*, *B*, and *C* show the attitude of the airplane with respect to the reference maintained by the gyros. This information is necessary to the pilot when automatic control is being engaged. The double-throw switches *D* and *E*, below the indicators, are for aileron and elevator control, and are used to trim the automatic control to the desired attitude before engagement, and to control the attitude of the airplane while the automatic pilot is engaged. The selector switch *K* allows the pilot to utilize the P.D.I. to displace the reference maintained by

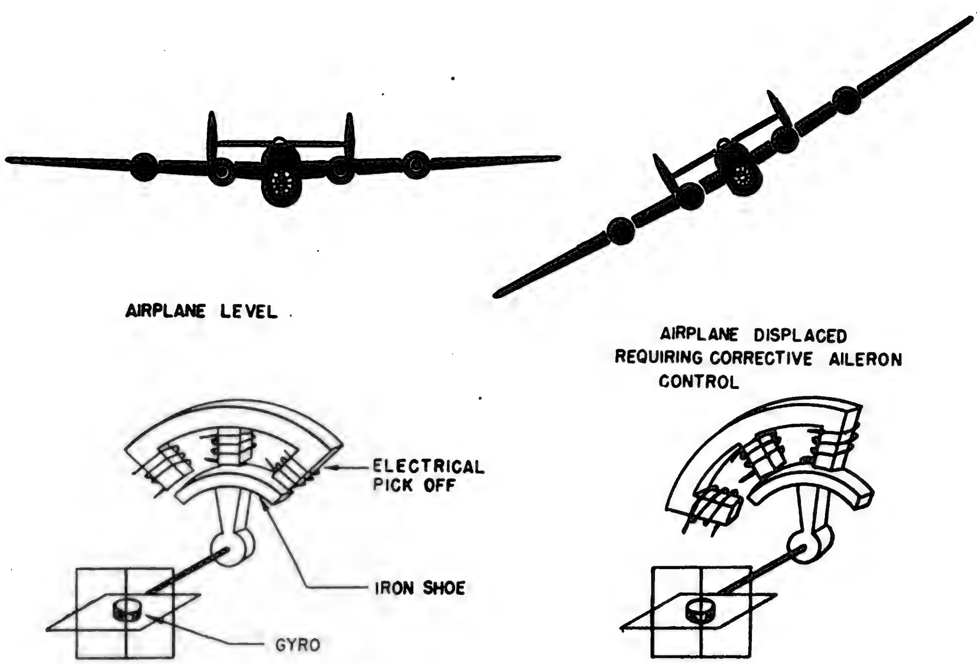


Figure 166. Electrical pick-off.

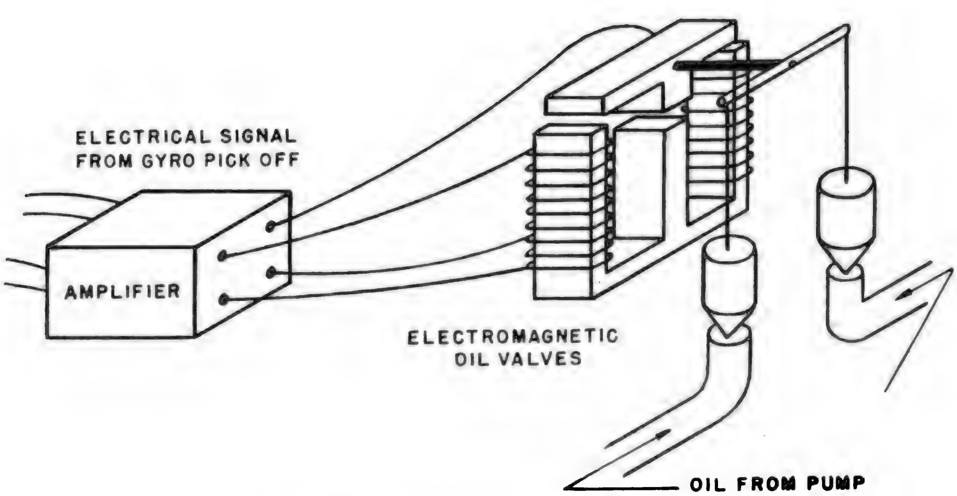


Figure 167. Schematic drawing of oil valves.

the directional gyro. The switch *F* is locked in the "Off" position and therefore is not used. The master control switch *I* has four positions, 90° apart, which are marked: "Off", *1, 2,* and *3*. Positions

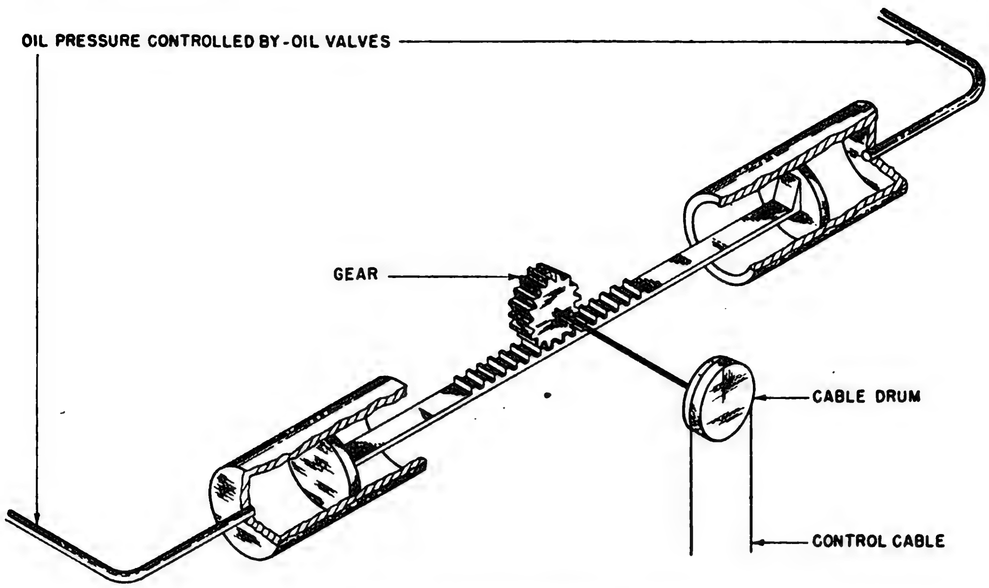


Figure 168. Schematic diagram of servo.

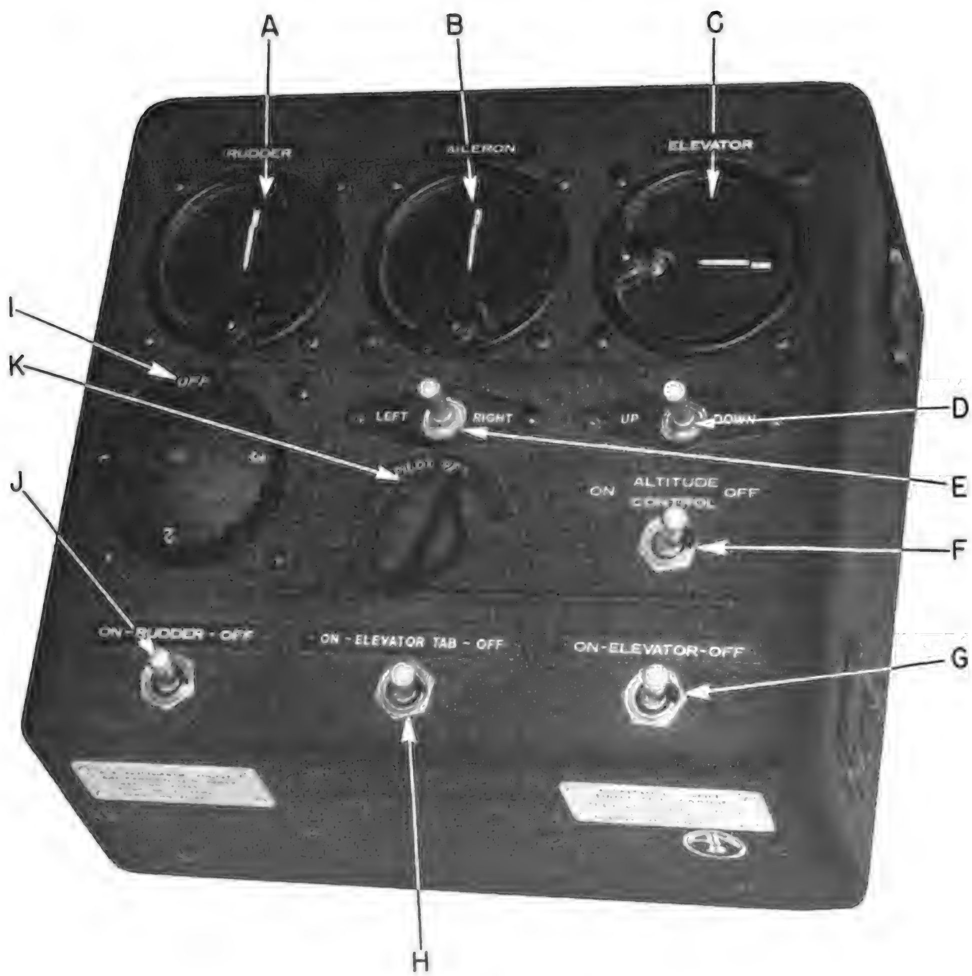


Figure 169. Control unit.

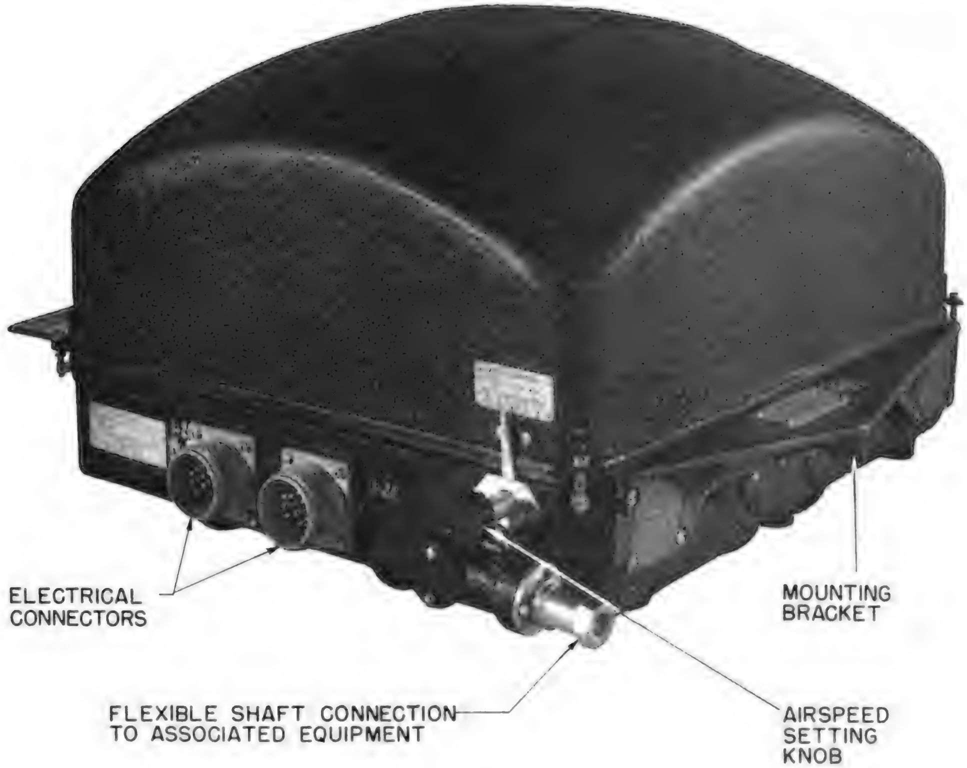


Figure 170. Vertical-gyro unit.

1 and *2* are the starting and warm-up positions; position *3* automatically engages aileron control. Switches *J* and *G* engage rudder and elevator controls respectively. Changes in heading or turns may be made by using the pilot's turn-control knob on the panel.

Figure 171. Directional gyro unit.

c. The vertical-gyro unit (fig. 170) contains the vertical gyro, its associated electrical pick-offs, and erecting equipment. It is mounted so as to be accessible to one of the crew members. In order to maintain proper banking ratio when the aileron control is handled by the associated equipment, a knob and scale is provided to set the equipment to the true airspeed.

d. The directional-gyro unit, in figure 171, contains the directional gyro, electrical pick-offs, follow-up, and leveling equipment. It is mounted near the associated equipment with electrical leads long enough to permit its removal from the mount and its installation on the associated equipment. Two wing screws facilitate easy removal.

e. The amplifier rack (fig. 172) contains the three servo amplifiers, the follow-up amplifier, the altitude-control unit, the altitude-control amplifier, a voltmeter, and frequency meter. It is mounted so as to be in view of one of the crew members. The servo amplifiers build up the weak electrical signals to sufficient strength to operate the servo valves.

f. Each of the three main servo units (fig. 173) contains a d-c electric motor driving a three-gear pump. The pump operates continuously while the automatic pilot is "On" (position *1, 2,* or *3* of the engaging switch) and supplies two equal streams of oil. A pair of electrically operated valves regulate the relief of the oil to the reservoir. When

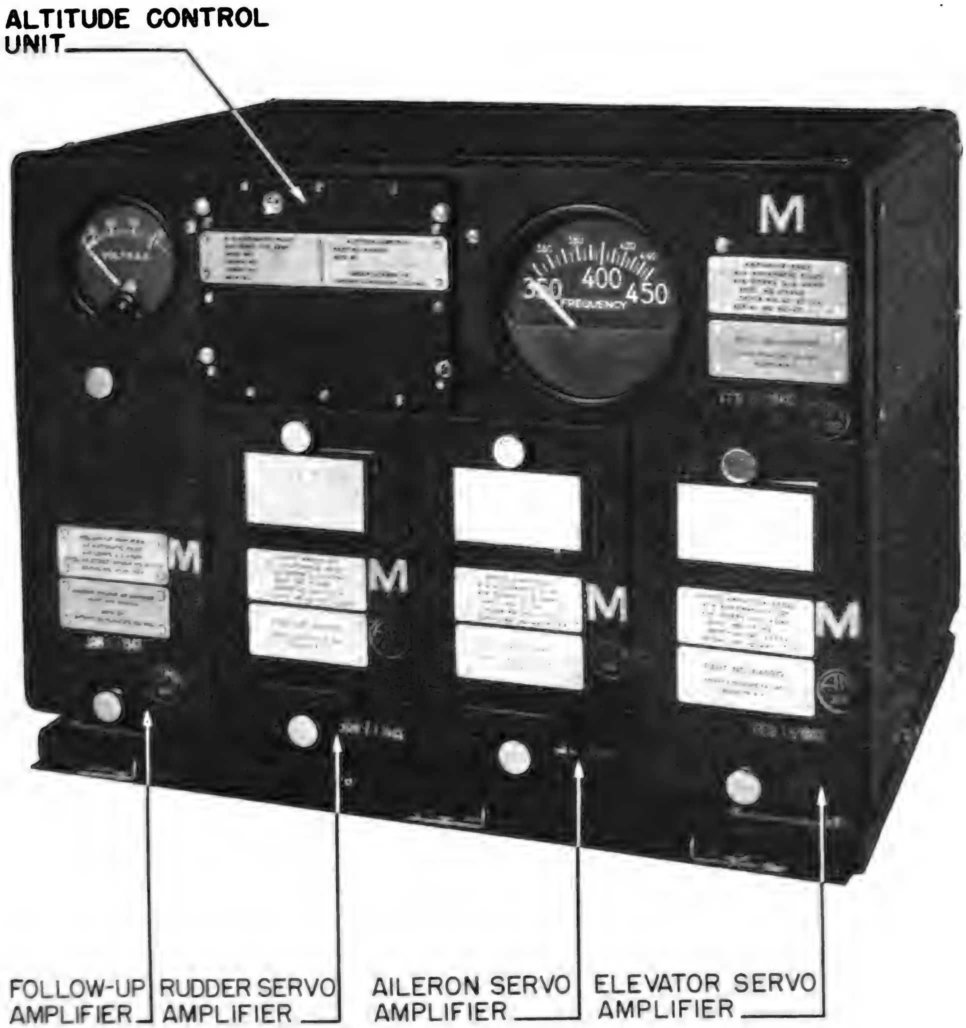


Figure 172. Amplifier rack.

an electrical signal unbalances the solenoids, one of the valves is opened and the other closed, so that unbalanced pressure is built up on the two servo pistons. This causes the pistons with the rack to move, driving the pinion gear which causes the cable drum to rotate. Reserve servo oil is contained in the housing, so that the need for a separate sump and perfect seals, around pistons and valves, is unnecessary. Two filters prevent dirt from entering the hydraulic valves. To remove the filters for cleaning, it is necessary first to remove the rear cover plate. A thermostat controls an electric heater, which in extremely cold weather, keeps the oil of the servo warm enough to flow properly. The heater is connected to the main switch of the airplane. A mechanical emergency release is operated by a cable from the pilot's position. The locations of the servos vary in different airplanes according to convenience. Servo units of different power and pulley sizes are available to accommodate the particular installation.

g. The pilot director indicator, shown in figure 174, is mounted on the instrument panel, directly in front of the pilot. It furnishes a visual direction reference obtained from the directional gyro of the auto pilot when the rudder control is being handled by the human pilot. The station selector switch must be turned to the P.D.I. position for this system of operation.

h. The pilot's turn control (fig. 175) is generally located on the instrument panel near the automatic pilot control panel. It is usually in a position so that both the pilot and copilot can reach it. The turn control provides the human pilot with a means

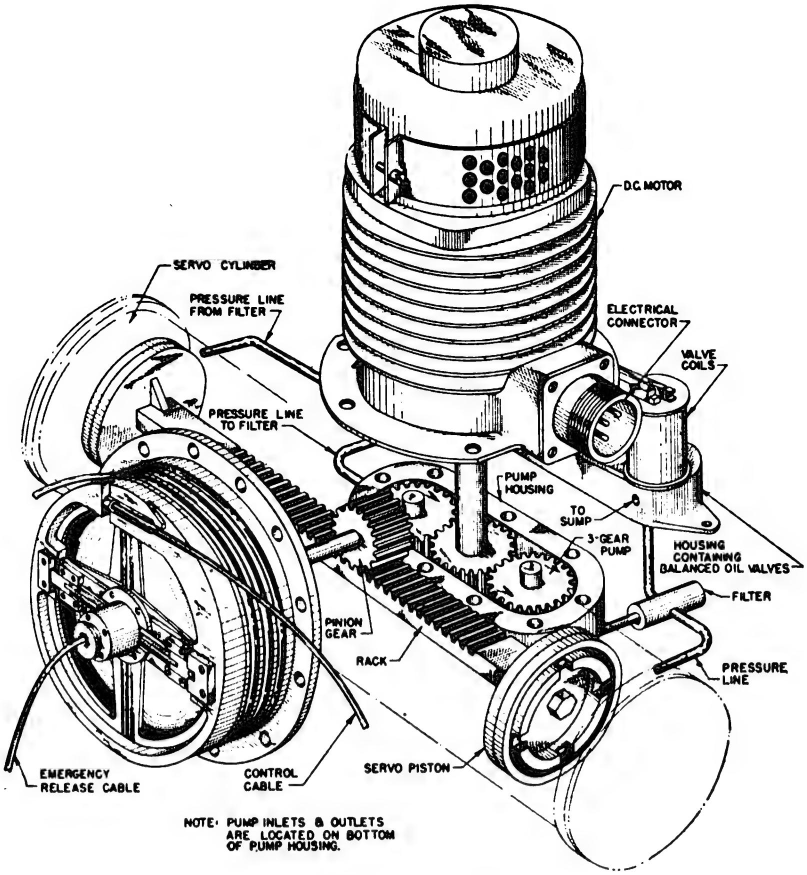


Figure 173. Servo-unit schematic.

of making banked turns through the automatic pilot. By rotating the turn control knob, the pilot may set in signals for a turn of a desired magnitude and a proportional amount of bank.

Figure 174. Pilot director indicator.

68. Installation

a. Installation of the automatic pilot is performed at the airplane factory or at a major repair depot in accordance with Army Air Forces Specifications. The location of the units (fig. 176) varies with the design of the airplane. Servos of 0.1 and 0.2 horsepower with 4- or 6-inch pulleys are employed to accommodate small or large installations. When the servos are located an excessive distance from the amplifier, relay units are used.

b. The automatic pilot requires a source of electrical power of both 27.5 ± 0.5 volts direct

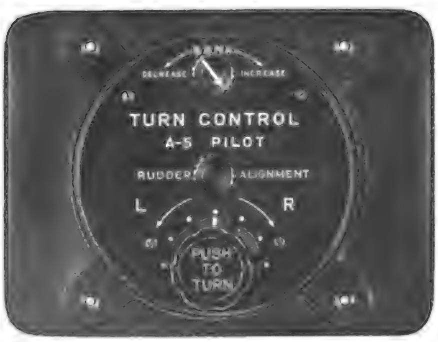


Figure 175. Turn control.

current and three-phase, 115 ± volts, 400 cycles, alternating current. The alternating current is supplied by a rotary inverter, which may supply power also for the autosyn instruments, fluorescent lights,

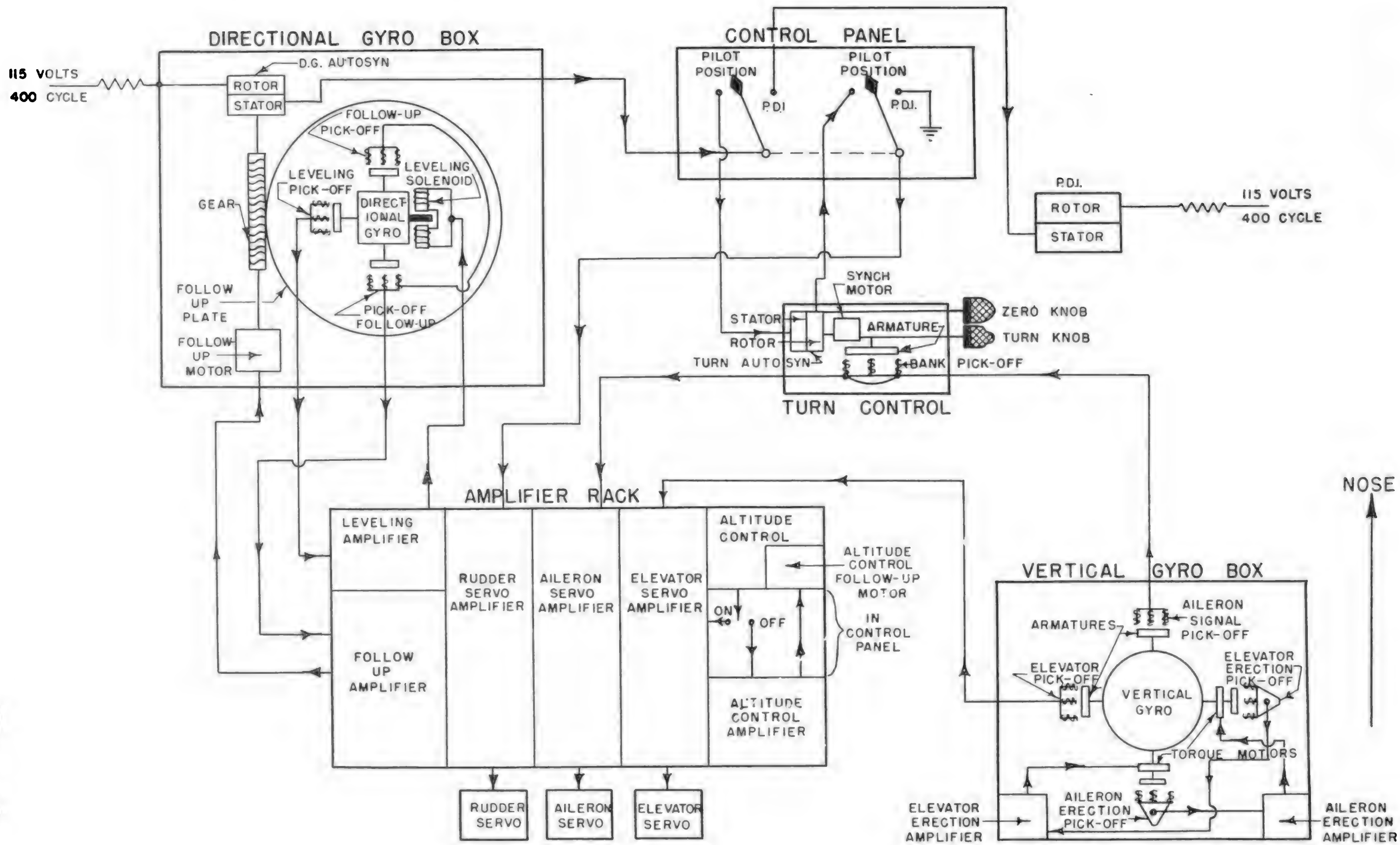


Figure 176. Simplified installation diagram.

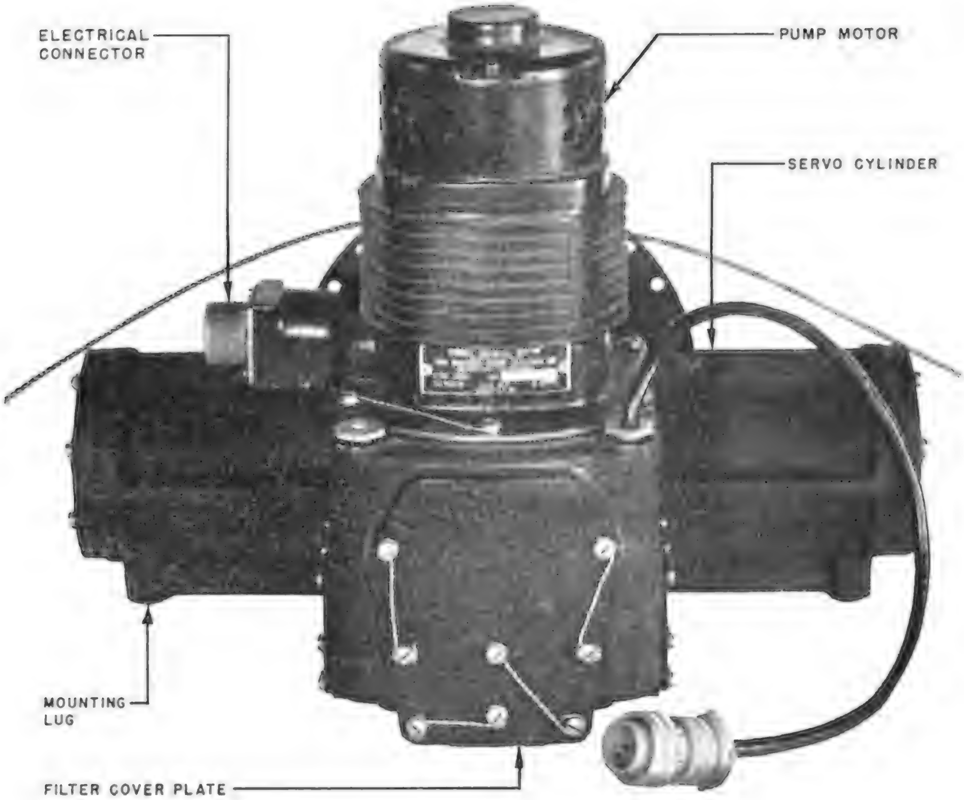


Figure 177. Servo—front view.

and remote-reading compass. The direct current is supplied by the airplane battery system.

69. Inspection and Maintenance

a. The maintenance, which may be performed by the airplane crew, is limited by the training of the personnel. Maintenance of the servo units and all external mechanical features usually can be accomplished by the airplane crew, but most inspections, repair, and replacements of parts of gyro units and amplifiers require specialized training.

b. GROUND TEST. A ground test of the automatic pilot may be performed according to the following procedure during engine warm-up:

(1) The automatic pilot requires a power supply (including the power for the inverter) of from 50 to 75 amperes, depending upon which servos (0.1 to 0.2 horsepower) are used during normal operation. Cold starting currents may run as high as 160 to 270 amperes (−50° C.). Thus an external power supply is necessary if testing requires more time than the normal warm-up period. The voltage indicated by the a-c voltmeter on the amplifier unit should be 115 volts ±5 volts, and the frequency 400 cycles ± 20 cycles.

(2) Turn the master control switch *I*, (fig. 169) clockwise to position 1 (Off, 1, 2, and 3 are at 90° intervals on the switch) and leave it there for 20 seconds to allow the tube filaments to heat up.

(3) Turn the same switch clockwise to position 2. Operate all three controls manually to check for control movements.

(4) Turn the station-selector switch *K* to Pilot position.

(5) Be sure that the rudder "On-Off" switch *J* and elevator "On-Off" switch *G* are turned off. (The altitude control switch is locked in the "Off" position.)

(6) After 3 to 5 minutes, line up the needles of the aileron and elevator meters *B* and *C* by operating their respective aligning switches *D* and *E*.

(7) Line up the needle of the rudder meter *A* as follows: if the meter needle shows left deflection, turn the pilot's control knob *L clockwise* until the meter needle is centered; if the meter needle shows right deflection, turn the pilot's turn control knob *L counterclockwise* until the meter needle is centered.

Caution: If the meter needle shows no deflection, and clockwise rotation of the pilot's turn-control knob *L* does not give right deflection of

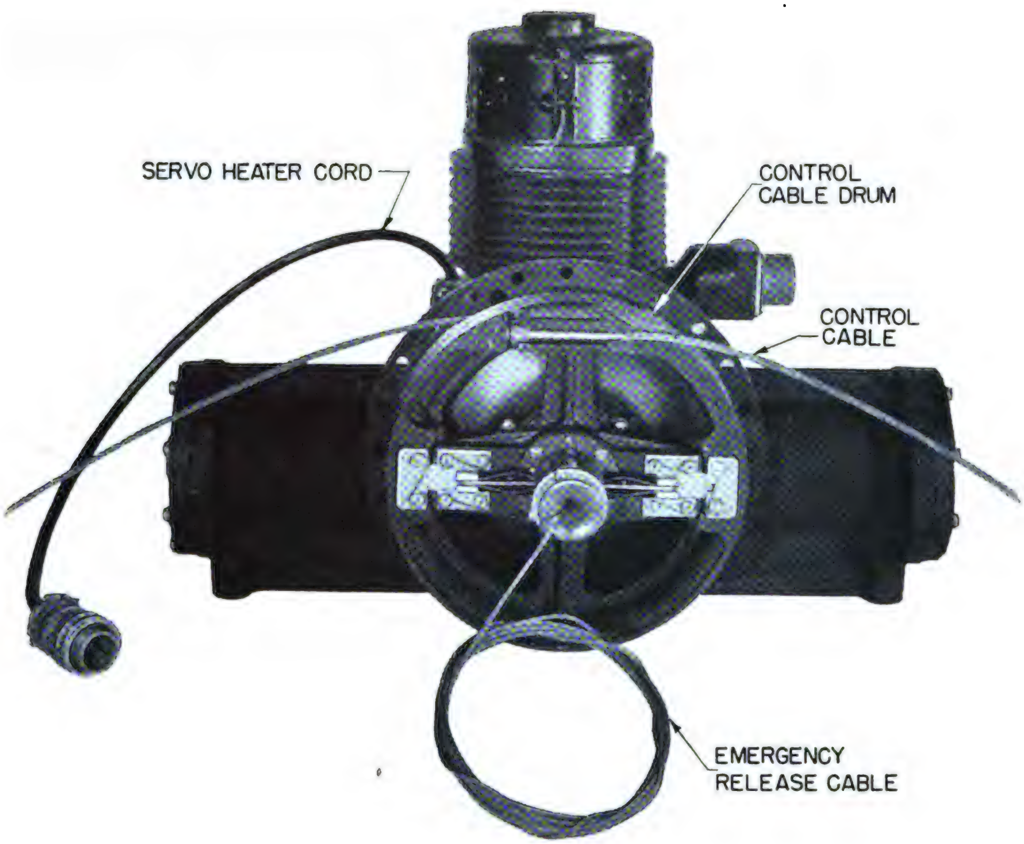


Figure 178. Servo, showing attachment of control cables.

the meter needle, continue turning the knob clockwise until the meter needle is centered.

(8) Turn the main switch knob *I* clockwise to position 3; this engages the aileron servo. (See figs. 177 and 178.)

(9) Turn on the rudder "On-Off" switch *J* and the elevator "On-Off" switch *G*. This engages the rudder and elevator servos, shown in figures 177 and 178.

(10) With hands and feet on the controls to prevent any sudden movement, operate the aileron aligning switch *E*, the elevator aligning switch *D*, and the pilot's turn control knob *L* to see that there is a signal of the proper direction on the controls.

(11) Press the emergency-release button on the control wheel and operate the aligning switches *D* and *E* and the pilot's turn-control knob *L* to make certain that all controls are freed.

(12) Turn all switches off.

c. Servo Filters. The two filters in each of the main servo units are cleaned at specified intervals. The following instructions outline this procedure:

(1) Drain the oil from the servo by removing the drain plug.

(2) Remove the plate opposite the pulley by removing the attaching screws.

(3) Remove the exposed filters and wash them in carbon tetrachloride.

(4) Replace the filters and plate; safety the attaching screws.

(5) If the oil shows signs of foreign matter, replace it with new oil. The oil level in the servo case should be between the marks on the gauge rod.

d. Servo Brushes. Access to the brushes of the servo motors for cleaning may be gained by removing the cover band from the top of the motor.

e. Security of Mounting. The units are checked for security of mounting by inspecting each mounting bolt (shock mounts on the amplifier). Servo units especially should be checked for looseness of attaching bolts or mounting brackets.

f. Emergency Release. To test the emergency release, the automatic pilot must be in operation (position 3 of the master switch) and the elevator and servo switches must be on. With the controls restrained as much as possible, apply partial signal

to all three controls with the aligning switches and pilot's turn control knob. Pull the emergency release handle and see that all controls are freed. If the release does not work properly, the release cables and pulleys should be checked throughout their length for undue wear, corrosion, or lodged foreign bodies. A few drops of oil may be needed on the release mechanism of the servos to permit smooth operation.

g. LUBRICATION. The gyro-assembly pivots normally require lubrication only when the units are removed for overhaul. In hot, dry climates, however, the oil evaporates abnormally and it is necessary to lubricate the accessible pivots more often. The gyro covers are removed, and a drop or two of gyro instrument oil is applied to all accessible pivots. About ten drops are required at each of the rotor bearings.

h. CONTROL CABLES. The cables and pulleys are inspected at prescribed periods for freedom of operation, proper tension, alignment of pulleys, anchorage, frayed or unduly worn cables, and safetying.

i. TROUBLES. (1) If none of the servo motors start during the warm-up period (position 1 of the master switch), failure or low voltage of the d-c supply or failure of the relay in the top of the amplifier rack is the probable cause.

(2) If only one servo motor fails to start, an open circuit in the d-c line to the servo or failure of the motor itself is likely.

(3) Hard-over control by one of the servos during warm-up (position 1) may be caused by dirt in one of the servo valves. (The remedy is to remove and carefully clean the valves.) To do this, the motor housing must first be removed.

(4) Flutter of the control surfaces during flight may be caused by dirt in servo valves and may be remedied by cleaning.

(5) Wallow, or hunting of the controls, may be caused by excessive friction of the control cables, since the number of degrees of the "dead spot" is directly proportional to the amount of friction.

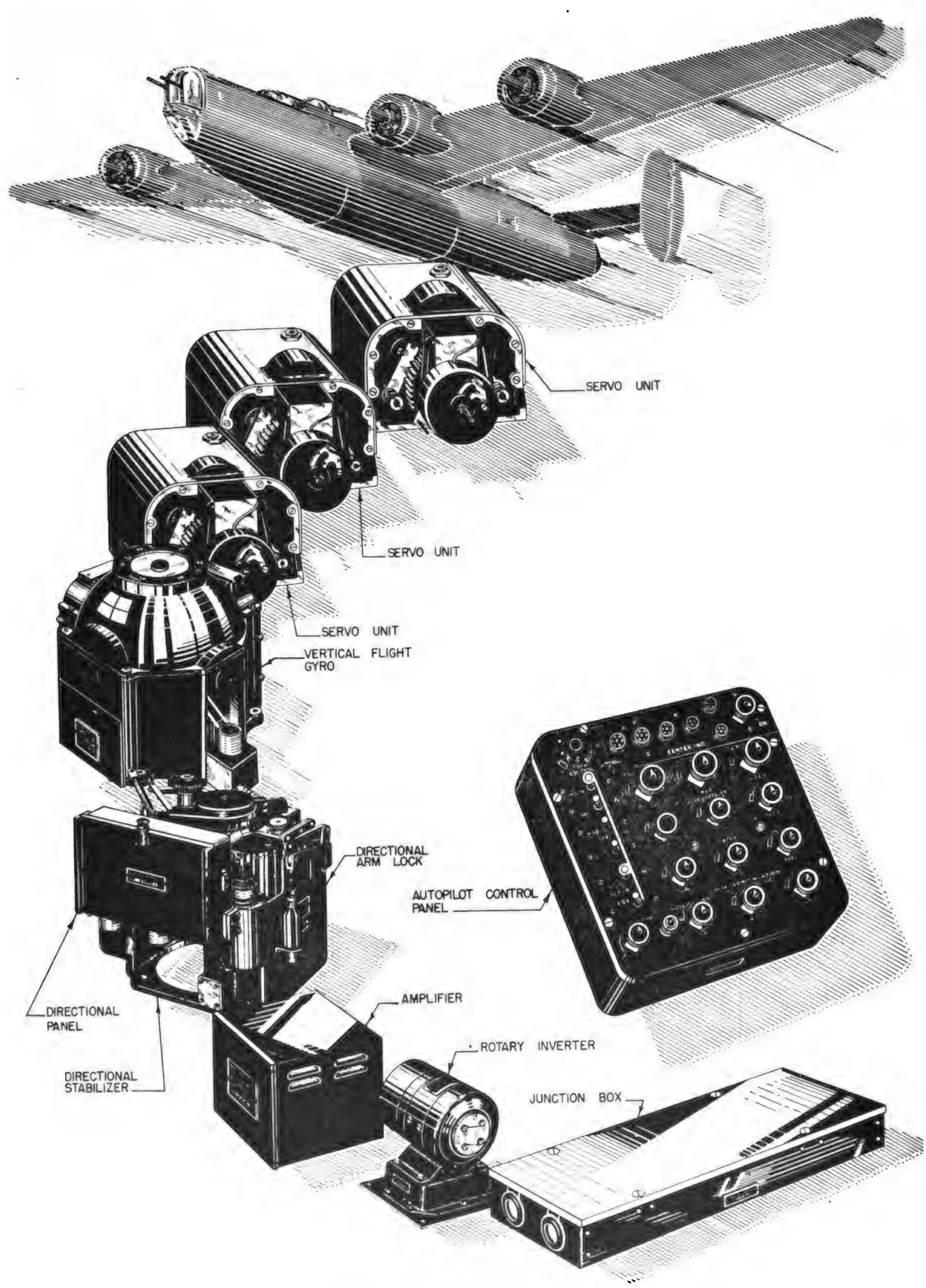


Figure 179. C-1 automatic pilot.

SECTON XIV
TYPE C-1 AUTOMATIC PILOT

70. General

a. PURPOSE. Figure 179 illustrates the major units employed in the C-1 autopilot installation. The autopilot as installed in bombardment aircraft has a two-fold duty to perform. It provides (through accurate, automatic control of the airplane's movements) as shown in figure 179, the stabilized aerial platform which is essential in high-altitude precision bombing. It also serves to relieve the pilot of much of the tiresome, routine work involved in keeping the airplane level and on course. It is especially valuable on long missions during which the human pilot may become so fatigued that he will fail to respond rapidly enough to the indications shown on his instruments. When properly set up and engaged, it will detect immediately any slight variations in the airplane's course or attitude and will apply the exact amount of control needed to return the airplane to its correct position. The action of the C-1 autopilot in returning an airplane to its original heading is smoother, more accurate and more rapid than the action of the human pilot. This is because such factors as pilot fatigue and the slowing down of reaction time do not affect the autopilot. In correcting deviations of the airplane, the autopilot fully coordinates all three control surfaces to give the desired movements, without either undershooting or overcontrolling.

b. USE. In addition to the two main functions, the C-1 autopilot may be used to assist the human pilot in a number of other ways. Through the use of the turn control, completely coordinated banked turns of any desired degree up to 40° bank are obtainable. The bombardier, by using controls provided on his equipment, can also cause completely coordinated turns up to 18° bank. The autopilot can be set so that it will regulate the action of one, two or all three of the airplane's control surfaces, or any combination of these. The main autopilot control panel provides means for adjusting the response and sensitivity of automatic pilot operation to suit any slight change in load or trim of the airplane which may be encountered during flight.

71. Fundamental Operating Principles

a. GYROSCOPE THEORY. The basic signals for automatic control of an aircraft in flight must be derived from some reference system which will at all times remain relatively fixed with regard to the surface of the earth, regardless of the movements of the airplane in which it is carried. In the C-1 autopilot, these references are provided by two gyroscopes, one of which is shown in simplified form in figure 180. Essentially, a gyroscope con-

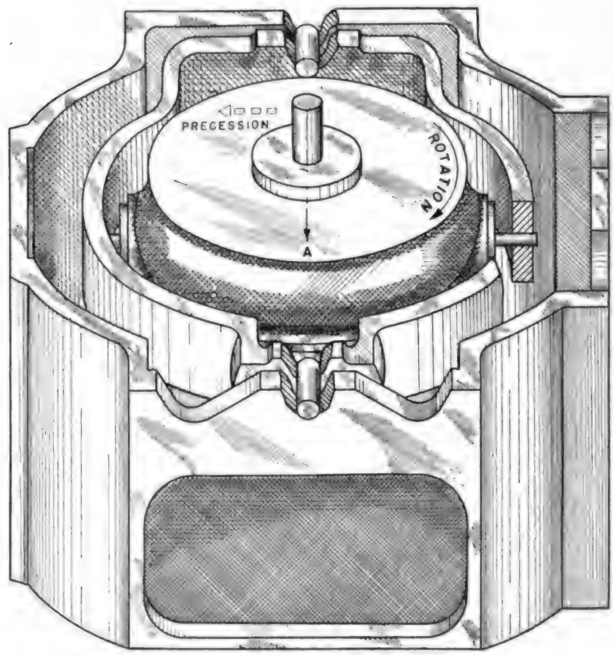


Figure 180. Simplified drawing of C-1 autopilot gyro.

sists of a universally-mounted, heavy, balanced rotor, which is spun at a high rate of speed. The gyros used on the C-1 autopilot are fastened directly to the armatures of small electric motors. The whole assembly is mounted into a set of pivoted rings which form a universal joint. This allows the gyro-motor assembly to tilt in any direction. If such a gyro is made to rotate at its correct operating speed, it will be found to possess two separate and distinct properties both of which are put to use in maintaining the flight references referred to above.

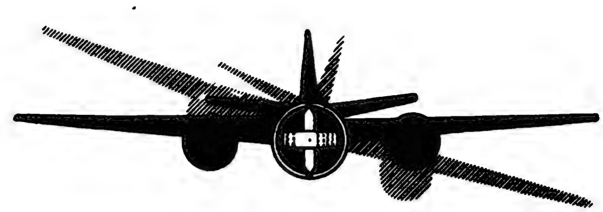
(1) *Rigidity.* The first and most important of these properties is called gyroscopic inertia, or "rigidity." This means that, while spinning, the gyro rotor will tend to maintain or hold itself (and its axis) fixed in any position in which it may be

placed, and will resist any force applied to it in an attempt to change this position. In the C-1 autopilot, the case and rings in which the gyro is mounted, enable it to do this. No matter which way the airplane should bank or pitch around the gyro shown in figure 180, the gyro rotor would remain in a horizontal plane and the axis or spindle would remain perpendicular to the earth's surface. Once stabilized in this position, the gyro can be used to supply a reference point against which movement of the airplane in either roll or pitch axis can be detected. Similarly, a gyro mounted and stabilized with its axis or spindle horizontal and pointing in a given direction can be used to pick up any changes in the rudder course of the airplane. The use of two gyros to detect the motion of the airplane about each of its three axes is shown in figure 181. Figure 181(1) and 181(2) show the action of the vertical flight gyro and figure 181(3) shows the action of the directional stabilizer gyro.

(2) *Precession.* The second property possessed by the gyro is called "precession." This term refers to the peculiar manner in which the gyro will react if any attempt is made to move it from the position in which it is maintaining rigidity. Precession in a sense, may be defined as the tilting of a gyro at right angles to the direction in which a force is applied to it. If a slight downward force be applied to the gyro at the point A (fig. 180), the gyro will react, not by allowing the inner case to move downward in the direction of the push, but by tilting the entire assembly to the left as shown. The amount of precession will depend upon the strength of the force applied, and reversing the direction of rotation of the gyro will result in reversing the precession. It should be understood that both rigidity and precession will be found only in a spinning gyro, and that an inoperative one would not possess either of these properties.

b. Operation of Bridge Circuits. Although the two gyros of the C-1 autopilot are capable of detecting the slightest changes in the airplane's course or position, they are unable to apply any corrective action until they have been connected (by a suitable signal pick-up system) to the other units of the autopilot. These connections are made through balanced electrical circuits called bridge circuits, which control the action of the servo motor units, and are in turn controlled by the gyros. Since the control and adjustment circuits are bridge circuits, it is important that their operation be understood.

(1) The bridge circuit is simply a system for measuring electrically the amount and direction of two motions. First, it is used to measure any movements of the airplane in going off course, by comparison with the fixed flight references set up by the gyros. Secondly, it measures and limits the amount of control surface movement applied by the autopilot as the airplane is returned to its course. Since there are two separate motions to be measured by the bridge circuit, there must be two separate electrical measuring devices for each axis. These devices, called potentiometers or "pots," are made up of a circular winding of resistance wire and a



(1) About the longitudinal axis.

(2) About the lateral axis

(3) About the vertical axis.

Figure 181. How the gyros control the autopilot.

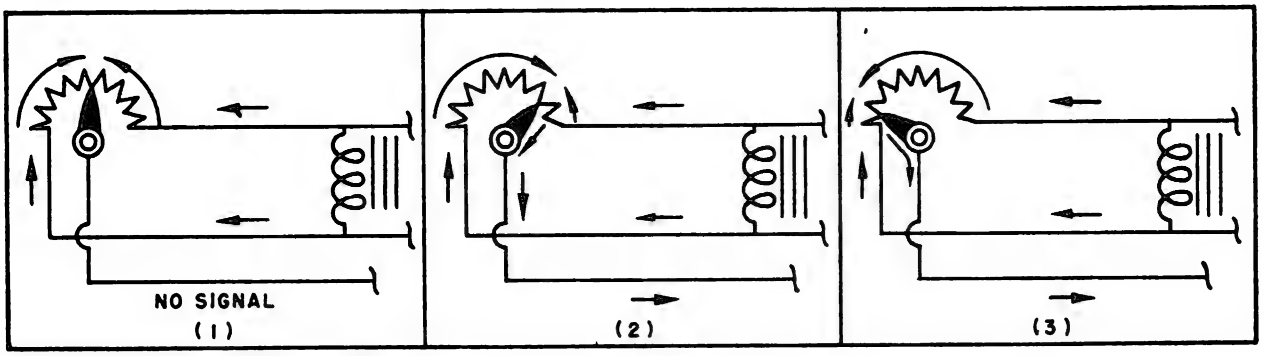


Figure 182. Operation of potentiometer.

movable contact arm or "wiper." A-C power is supplied across the ends of the pot winding from a special transformer. Any signal (electrical unbalance) resulting from movement of either the wiper or the winding is picked up by the wiper. The operation of such a potentiometer is shown in figure 182. When the wiper is centered on the pot winding as shown in fig. 182 (1), no signal results. This occurs whenever the airplane is trimmed to match the exact electrical balance of the autopilot system, and no correction will be set in. Figure 182 (2) and 182 (3) show the effect of unbalancing the system by moving the wiper right and left of center. Notice that although in both cases the signal is picked up by the wiper, the direction in which the signal flows in figure 182 (2) is opposite to the direction taken by the signal in figure 182 (3). This is due to the fact that the wiper was moved across the electrical center of the winding each time the circuit was unbalanced. (Although a-c is used in this circuit, the effect obtained is the same as if d-c were used. In one case a plus (+) signal is produced and in the other a minus (—) signal is produced.) Either the wiper or the winding may be moved to unbalance the circuit without changing its operation in any way.

(2) Two of these potentiometer units may be combined, as shown in figure 183 (1), to form a simple bridge circuit. The bridge circuit will operate in the same manner as the pot circuits, but it must be remembered that now either of the two pots can balance or unbalance the system. To rebalance the bridge circuit electrically, it is not necessary that each of the pot wipers be in the exact mechanical center of the pot winding. If one pot wiper is displaced, as shown in figure 183 (2), the circuit may be rebalanced by moving the second pot wiper an equal amount. (See fig. 183 (3).) Figure 184 shows schematically, the arrangement of the units of a bridge circuit for elevator control. Pot (A) has its wiper fastened to the gyro, and its pot winding fastened to the airplane, so that any motion of the airplane away from the elevator course being

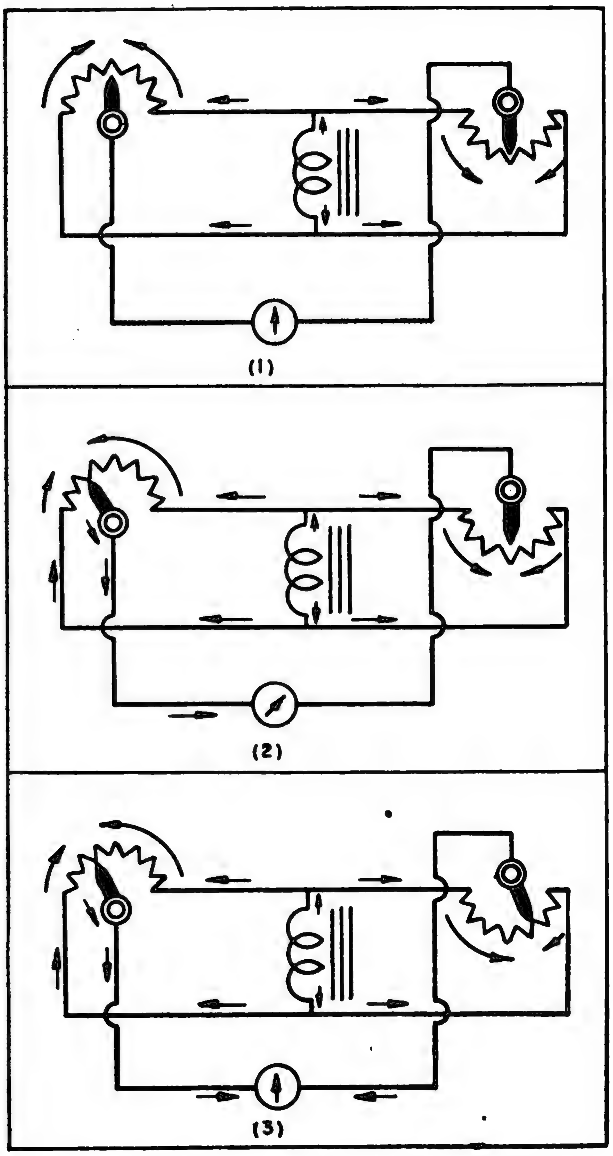


Figure 183. Operation of simple bridge circuit.

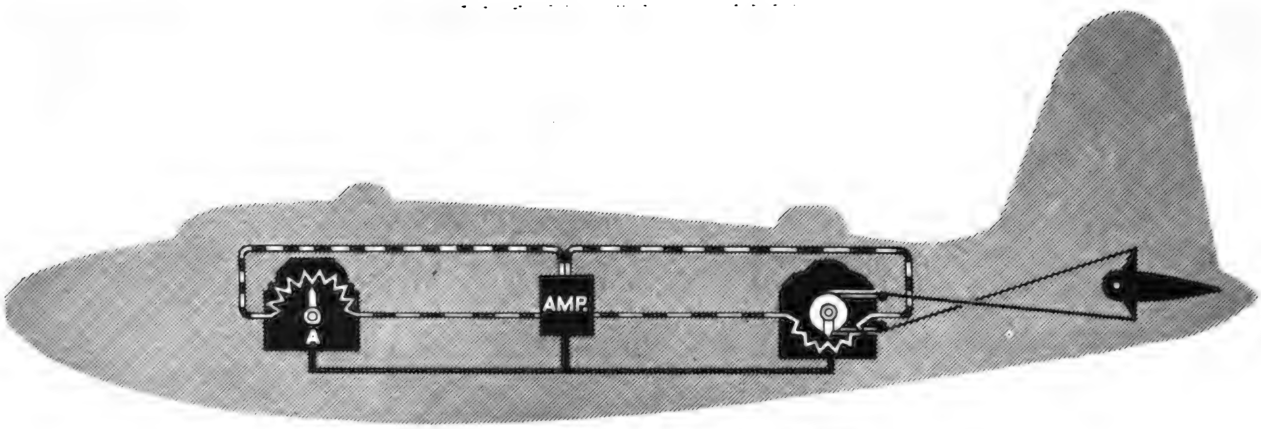


Figure 184. Arrangement of bridge circuit for elevator control.

held by the gyro, will unbalance the circuit. Pot (B) has its wiper connected mechanically to the elevator cable drum on the autopilot elevator servo unit. Any movement of the control surface will be picked up by this pot. If the airplane should go into either a climb or a dive, pot (A) would be unbalanced by a certain amount, which would result in a signal being sent to the servo motor to apply corrective elevator movement. But because of pot (B) on the cable drum, the servo unit will apply only the precise amount of elevator control called for by the gyro. As the cable drum rotates, the pot wiper attached to it will be moved to a position where its displacement is equal to that of the gyro pot. This will rebalance the circuit and cancel the signal to the servo, therefore movement of the elevator will be stopped. In this way, any tendency of the autopilot to apply too much or too little control is eliminated. Similar arrangements are used for the bridge circuits controlling the ailerons and the rudder.

72. Operating Units of Autopilot

a. Vertical Flight Gyro (VFG). (1) *Purpose.* The vertical flight gyro, shown in figures

Figure 185. Vertical-flight gyro.

185 and 186, is used to provide the C-1 autopilot system with references for controlling the move-

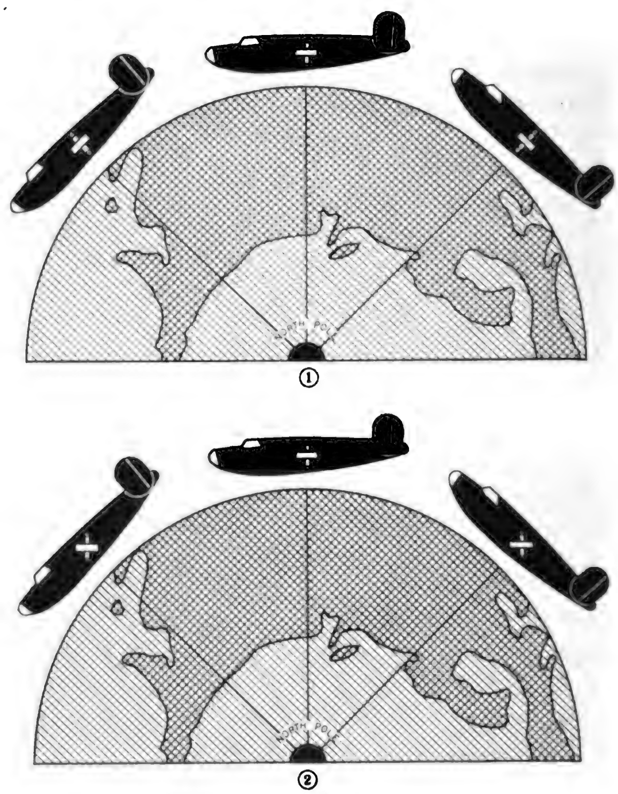
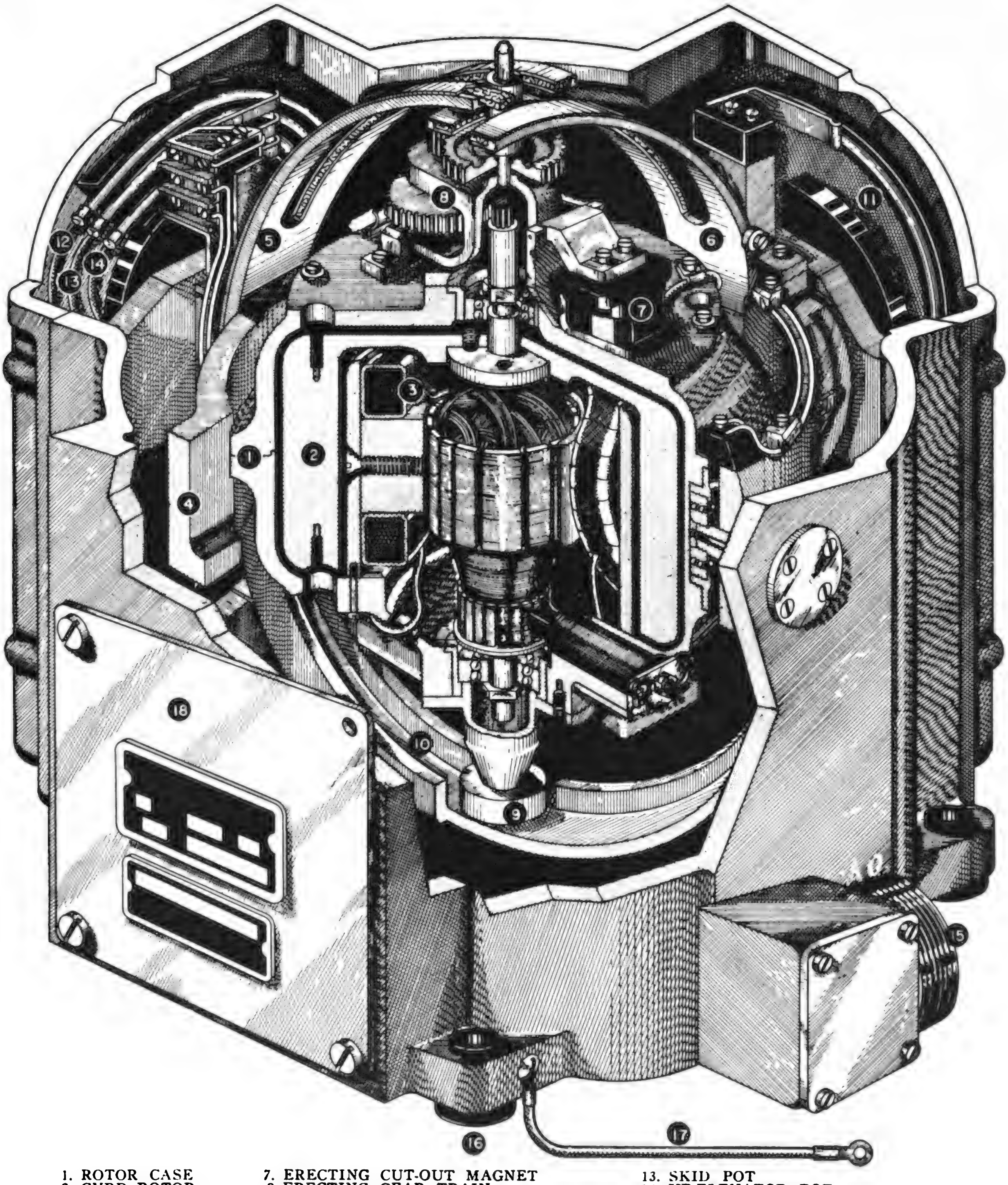


Figure 187. Action of free and modified gyro.

ments of the ailerons and elevator. It is operated electrically from the airplane's d-c supply, and runs at a speed of approximately 7,500 rpm.

(2) Gyro. To establish the necessary rigidity, a heavy gyro rotor weighing about 4 pounds is used. Because of its rigidity and because it has been specially modified, this gyro will keep its axis or spindle perpendicular to the earth's surface at all times. A free or unmodified gyro does not possess this characteristic, and would be of no use in controlling an autopilot system. The reason for this is shown in figure 187. Figure 187① shows the



1. ROTOR CASE
2. GYRD ROTOR
3. FIELD COIL
4. CARDAN RING
5. TOP BAIL
6. BOTTOM BAIL
7. ERECTING CUT-OUT MAGNET
.8 ERECTING GEAR TRAIN
9. GUIDE ROLLER
10. COUNTERBALANCE GUIDE CHANNEL
11. ELEVATOR PICKUP POT
12. AILERON PICKUP POT
13. SKID POT
14. UP-ELEVATOR POT
15. A-N CONNECTOR (MALE)
16. RUBBER MOUNTING GROMMETS
17. GROUND WIRE
18. INSPECTION PLATE

Figure 186. Cut-away view of vertical flight gyro.

action of a free gyro as it would appear in an airplane traveling over the earth's surface. It can be easily seen that such a gyro will maintain its rigidity in space without reference to the earth below, while the airplane must necessarily follow the curvature of the earth as it flies along. As a result, the signals sent out by such a gyro would be incorrect.

(3) *Erection mechanism.* This difficulty has been

overcome by adding to the gyro, a corrective device known as the erecting mechanism. This device forces the gyro to keep its axis continuously perpendicular to the earth's surface, regardless of the movements of the airplane. (See fig. 187②.) In addition, the erecting device stabilizes the gyro against any external forces resulting from turns and other maneuvers, and it counteracts the effects of any small forces due to friction or unbalance which might be present in the gyro itself. The erecting mechanism used in the vertical flight gyro consists of the two slotted, cork-lined, semicircular bail rings which are shown crossing over the top center of the gyro in figure 186. These rings are loosely attached to the pivot shafts of the gyro mounting, so that they are free to fall from side to side. In the square space formed by the crossing of these rings, there are two small rollers. These rollers are mounted one above the other on a common spindle, and are driven from the gyro rotor through a set of reduction gears. These two rollers spin continuously at 1/32 of the speed of the gyro, one roller inside each of the bail ring slots. As long as the gyro axis remains vertical, the bail rings will be constantly moving back and forth, touching the rollers first on one side and then on the other. The gyro will not be affected by this movement, since the bails do not apply their force against the rollers for a long enough time. However, if the gyro should become sufficiently tilted in any direction, the bails will cause it to restore itself again to a vertical position. This action of the bail rings is shown in figure 188. In figure 188 (1), the gyro axis is vertical, and the bails have no effect, simply moving back and forth around their rollers. If the gyro is tilted, as in figure 188 (2), one or both bails fall against the rollers. The force exerted on the gyro by the actual weight of the bail ring is neutralized by a counterweight, but the friction between the cork lining of the bail slot and the roller will result in a second force being applied to the gyro in the direction shown. The gyro will react by precessing at *right angles* to this frictional force thus forcing itself back into a vertical position. (See fig. 188 (3).) Once in the vertical position, the bails will continue to touch the rollers intermittently, but this action will not disturb the gyro because the bails will continually precess it back to the vertical as soon as it tilts off far enough for the frictional force of the bail and roller to take effect.

(4) *Erection cut-out.* Due to the fact that the bail rings are loosely mounted, they can also be acted upon by certain other forces encountered during flight. For example, during a turn, centrifugal force will cause the top (fore and aft) bail ring to be thrown against the top roller. The resulting precession will cause the gyro to move from the vertical until its axis is perpendicular to the floor of the airplane instead of perpendicular to the earth's surface. To correct this fault (which would destroy the gyro's usefulness as an accurate reference) an erection cut-out (ECO) is used. This device automatically stops or cuts out the action of the top bail whenever the airplane is placed in a coordinated banked turn with the autopilot. Figure 189 illustrates the action of the erection cut-out. In

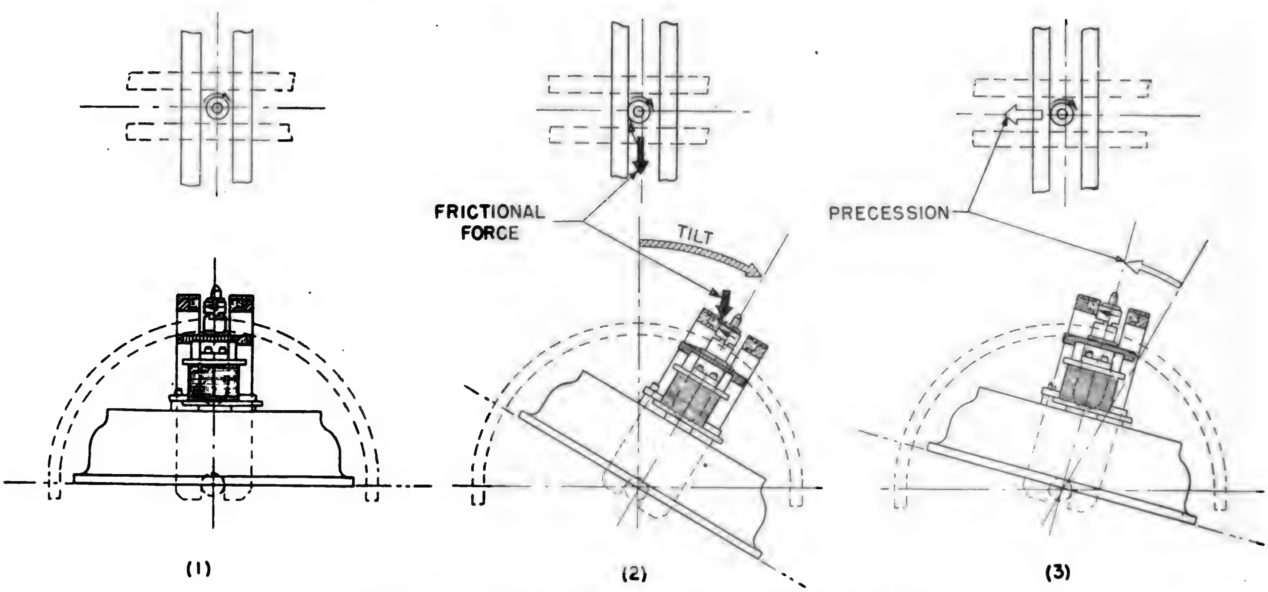


Figure 188. Action of bail rings in erecting vertical-flight gyros.

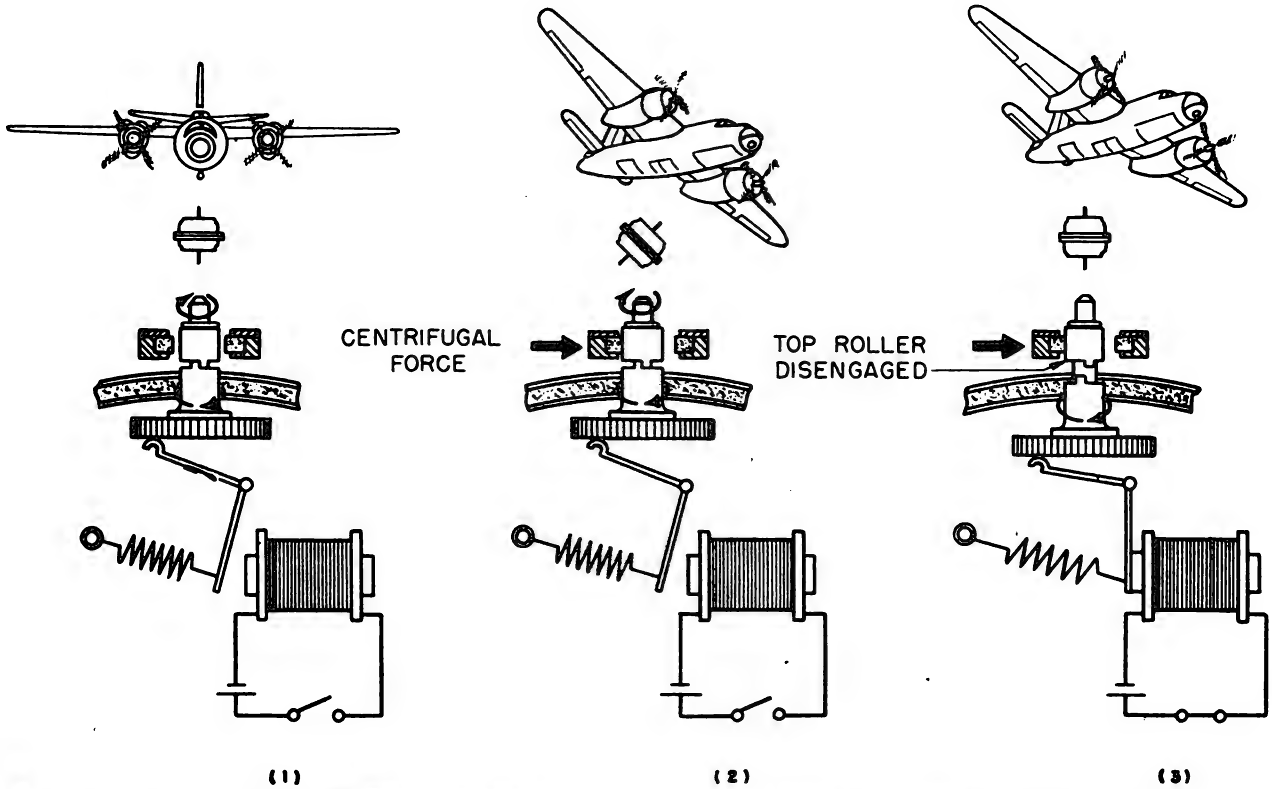


Figure 189. Action of erection cut-out.

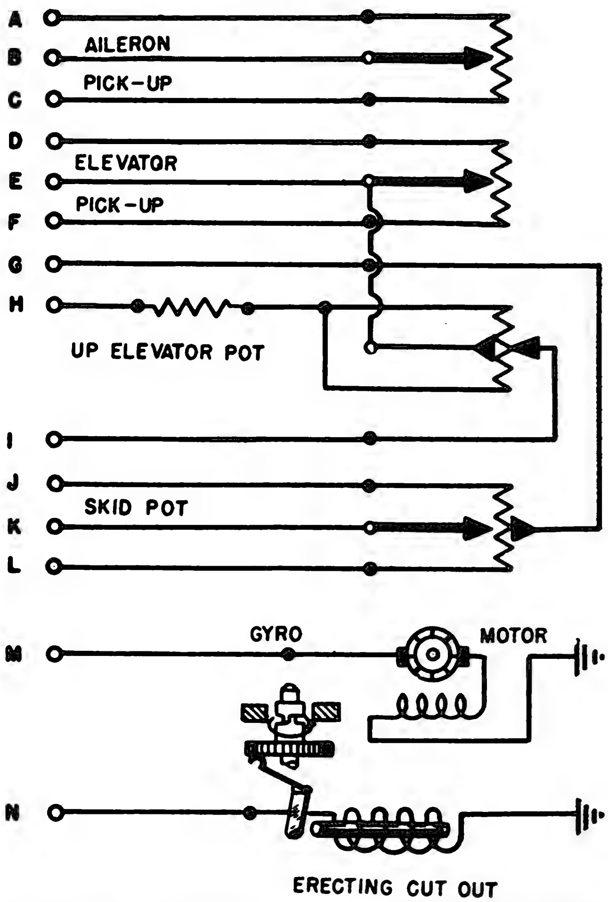


Figure 190. Schematic wiring diagram of vertical-flight gyro.

figure 189 (1), the airplane is maintaining a level course, and the top bail and top roller have no effect on the gyro. If the airplane is put into a banked turn, as in figure 189 (2), the top bail is thrown against the roller by centrifugal force. If it were not for the ECO, this would result in a frictional force which would cause the gyro to tilt as shown. When the ECO is energized by actuating the turn control of the ACP, its magnet is automatically energized at the same time that the turn is begun. (See fig. 189 (3).) This allows the bottom roller and gear to drop down the spindle and become disengaged from the top roller. When this occurs, the top bail is no longer able to cause any precession since the top roller stops spinning and no frictional force is applied to the bail. The gyro will therefore remain in an upright position during the turn. When the turn has been completed both rollers will again be engaged and the full action of the erecting bails and rollers will be restored. The bottom roller is never disengaged, since the bottom (lateral) bail is so mounted that the centrifugal force caused by turning of the airplane will not tend to throw it against its roller.

(5) *Pot assemblies.* Signals for elevator and aileron control are taken from the vertical flight gyro through two sets of pots, one set for each

control axis. (See fig. 190.) These pots have their windings attached to the outer case of the gyro unit and their wipers attached to the pivoted rings in which the gyro is mounted. The elevator pot is so placed that whenever the airplane moves around its lateral axis in climbing or diving, the pot winding moves with the airplane, while the pot wiper stays fixed with the gyro. As a result, the elevator bridge circuit is unbalanced, and a signal calling for elevator correction is set-up. The aileron pot is arranged in the same manner and sets up signals when the airplane moves about its longitudinal axis. However, while the elevator pot is a single pot supplying

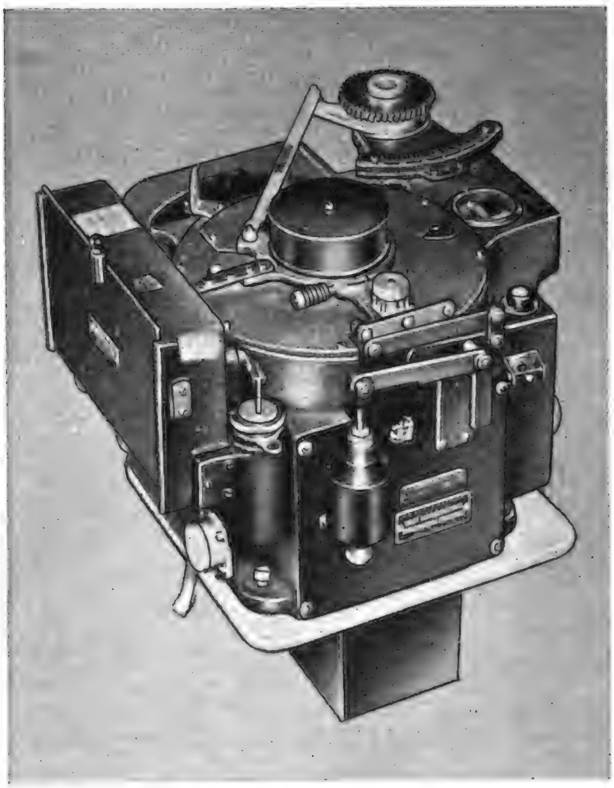


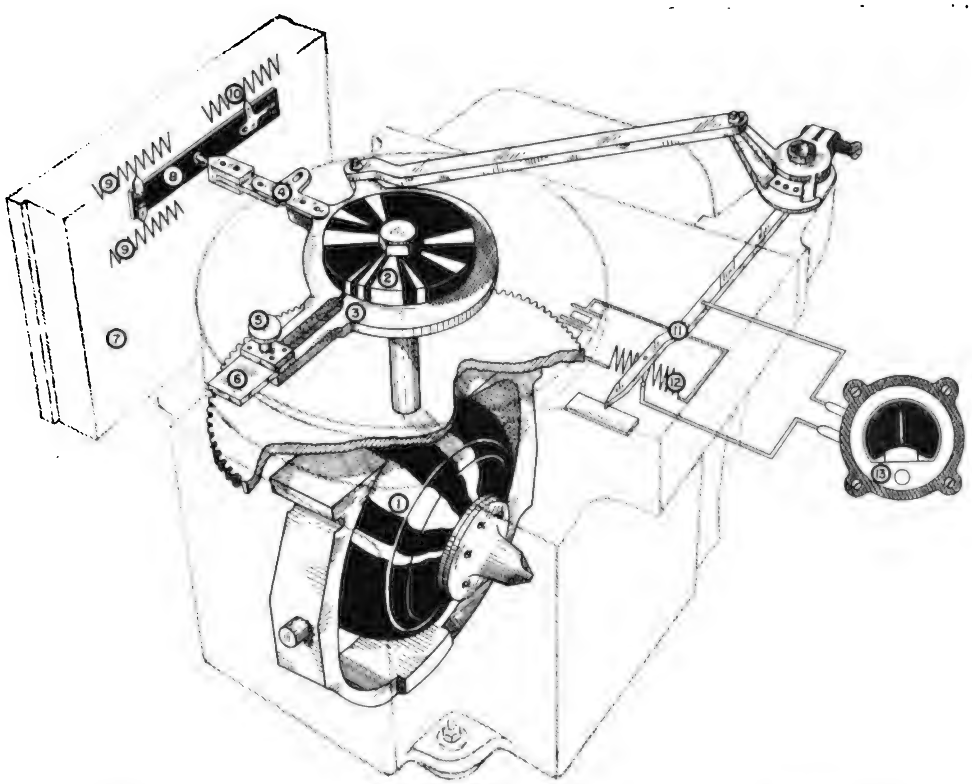
Figure 191. Directional stabilizer.

elevator control only, the aileron pot is a triple pot assembly. It is made up of three pot windings and three pot wipers, but works in exactly the same manner as the single elevator pot. In addition to the aileron pot itself, two other pots which are tied into the rudder and up-elevator circuits of the autopilot are added. If the airplane rolls, and only the single aileron pot were used, aileron correction alone would be applied to return the airplane to its attitude. As the ailerons move to apply this correction, the unequal drag set up by the right and left ailerons being above the wing on one side and below it on the other, will tend to turn the airplane still further off course. To compensate for this, the second or rudder pot is incorporated in the aileron-pot assembly to apply enough opposite rudder to neutralize this turning effect. The third or up-elevator pot is added to make up for any tendency of the airplane to lose altitude (as a result of the temporary loss of effective lifting surface) during the roll. All three pots move simultaneously, and as a result of these three combined signals, the plane is actually "banked and turned" back to its correct position. This action gives a much smoother and more accurate correction than would be possible with the aileron pot alone. The amounts of rudder and up-elevator control applied depend on the control characteristics of the airplane in which the autopilot is installed. These values are determined by actual flight checks, and the autopilot control panel is adjusted accordingly.

b. DIRECTIONAL STABILIZER. (1) ***Purpose.*** This unit (fig. 191) provides the reference used for automatic control of the rudder. It is also used by bombardier in connection with the bombsight for stabilizing the airplane's heading while approaching the target. Through it, he may also put the airplane into coordinated, banked turns. For this reason, the unit is mounted in the forward nose section of the airplane, where the bombardier has free access to it.

(2) GYRO. The gyro in this unit operates at a speed of approximately 7,700 rpm and is supported in a ring type, universal mount so that it can maintain its rigidity. Since the directional stabilizer is used to hold a given directional reference, its gyro is mounted so that the axis or spindle is horizontal. It will therefore tend to keep its axis in a given direction. The airplane, in going off course, will rotate around it, and thus set up an "off course" signal. The arrangement of the directional stabilizer and its gyro is shown in figure 192. A schematic wiring diagram of the directional stabilizer is given in figure 193.

(3) *Torque motor assembly.* Like the vertical flight gyro, the gyro in the DS must also be modified, so that it will maintain itself in the desired position, without being affected by external forces applied to it by the motions of the airplane. This is done by adding to the gyro an erecting mechanism known as the torque motor assembly. The action of this unit in leveling the directional stabilizer gyro is shown in figure 194. The torque motor itself is a small direct current motor attached to the stabilizer case. It runs continuously whenever the autopilot is in operation and drives two oppositely-rotating, cork-



1. Gyro.
2. Clutch drum.
3. Autopilot clutch.
4. Directional panel drive arm.
5. Engaging knob.
6. Clutch arm extention.
7. Directional panel.
8. Slide.
9. Aileron pots.
10. Rudder pot.
11. PDI wiper.
12. PDI pot.
13. PDI.

Figure 192. Directional stabilizer gyro and pot arrangement.

faced gears, each of which can be engaged to the rest of the correction system through the action of the magnetically operated clutch disks. As long as the gyro axis remains horizontal, the wiper (attached to the gyro case) will rest on the dead section of the contact plate (attached to the mounting ring), and the erection system will not operate. If the gyro should tilt away from the horizontal the wiper will be moved across the plate, closing a circuit and energizing one of the two clutch magnets. When this occurs the clutch plate associated with the magnet is pushed up against the cork-surfaced gear, causing a rotational force to be applied through the gears to the gyro mounting ring. This force will cause the gyro to precess at 90° to the applied force, therefore the gyro axis will move back toward the horizontal. As it again becomes level, the wiper will be recentered on the contact plate, opening the clutch circuit and eliminating the corrective force. If the gyro should become tilted in the opposite direction, the other clutch circuit would be energized, and a corrective force would be applied in the opposite direction. This corrective action takes place when the gyro is tilted from one to three degrees from the horizontal. However, if the gyro should tilt 3° or more, the wiper will touch one of the outside contacts. This will close a circuit applying current directly to the clutch magnets (without its passing through the series resistor) so that a larger amount of force will be transmitted by the clutch and the gyro will erect more rapidly. The stabilizer gyro motor and the torque motor are both operated from the airplane's direct current supply, but a separate switch is provided for each unit on the autopilot control panel.

(4) SIGNAL-PICK-UP SYSTEM. The directional stabilizer gyro, unlike the vertical flight gyro, has no pick-up pots and wipers directly connected to it. The signals are picked up outside the main gyro case by mechanisms linked to the gyro through the spring-loaded friction clutch attaching to the clutch drum show in figure 192. This drum is fastened to the gyro mounting ring, and therefore will not turn as the airplane turns. This clutch will slip at a tension of from 10 to 12 pounds, and is engaged by rotating the engaging knob clockwise. It serves to transfer any motion of the airplane picked up by the gyro to the wipers of the rudder and aileron pots

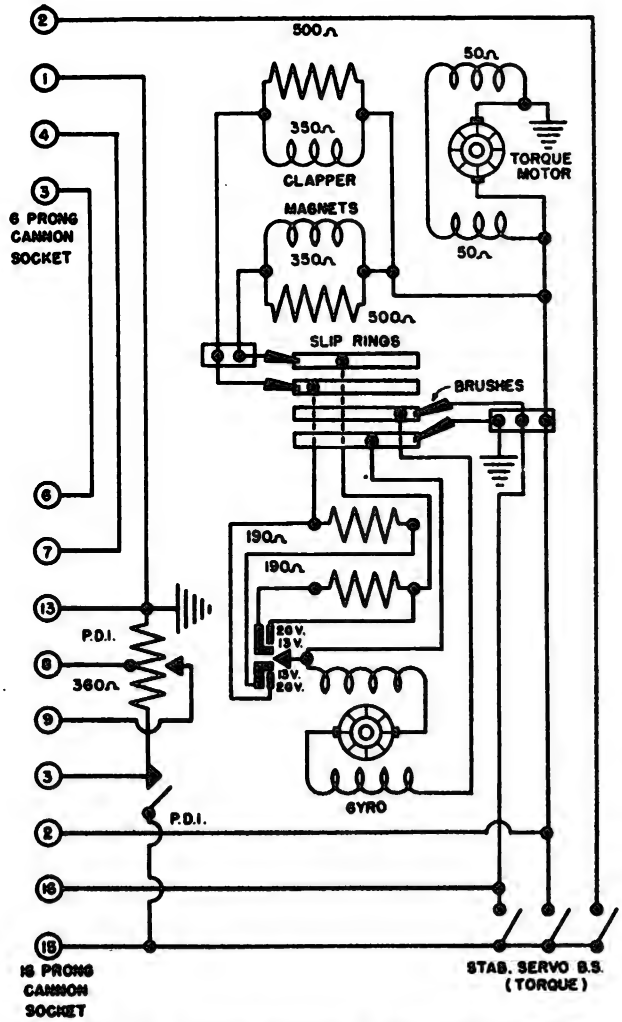


Figure 193. Wiring diagram of directional stabilizer.

in the directional panel. To provide the automatic rudder corrections necessary when using the bombsight, a second clutch is fastened to the drum in the same manner and is connected to the bombsight through a mechanical linkage not shown in the illustration.

(5) Directional Panel. This unit, which transfers all directional signals electrically to the autopilot system, is attached to the side of the directional stabilizer. Figure 195 shows the inside of the panel case. A schematic wiring diagram of the unit is shown in figure 196. The panel contains the rudder pot and two aileron (banking) pots, all of which are fastened to the case. The wipers for these pots are fastened to a slide which is attached to the autopilot clutch arm. This clutch arm extends through the back of the case and is not shown in the figure. The slide is also attached (by a mechanical linkage) to the piston of a liquid-filled dashpot on the end of the case. Each aileron pot is provided with a fixed contact which creates an electrical dead spot in the middle of each pot. When the airplane is "on course," each wiper is on the middle of its pot and no signal is set up. If the airplane changes course gradually, the rudder wiper is moved on the rudder pot and a signal calling for rudder correction is set up. At the same time, the aileron wipers are moved off the dead spot and a signal calling for aileron correction is set-up. The corrective movement of the controls returns the airplane to its course in a perfectly banked turn. If the airplane suddenly deviates from its course, the slide will be moved rapidly. As the rudder wiper is connected to the dashpot piston (which opposes rapid movement of the wiper), the force of the wiper restraining spring will be overcome and the wiper will rotate about the pivot. This rotation will result in increased movement of the wiper tip across the pot, therefore a stronger signal will be set up. The amount of restraining force exerted by the dashpot must be adjusted to suit the characteristics of the particular airplane, or the airplane will oscillate or "hunt." This adjustment is made by screwing the knurled cylinder on top of the dashpot in or out until the correct rudder response is obtained. The three wipers in the directional panel case may also be moved manually to put the airplane into banked turns of up to 18°. This is done by moving the knurled engaging knob of the autopilot clutch sideways, in the direction of the desired turn. When the turn has been completed, the wipers may be recentered by moving the knob back to neutral. The directional stabilizer will then hold the airplane on the new course.

(6) *Pilot director indicator (PDI).* To provide the pilot with a visual means of detecting any deviation of the airplane from the set rudder course, the motion of the autopilot clutch arm is also used to move a wiper across the winding of a separate pot, known as the PDI pot. This pot, which can be seen under the small circular coverglass on top of the directional stabilizer in figure 191, sends its signal directly to the PDI shown in figure 197, on the pilot's instrument panel. This instrument is simply a center-zero voltmeter, and will read right or left of its zero, as the airplane deviates from its rudder course and moves the PDI wiper across its pot.

(7) *Directional arm lock.* When it is desired to turn the airplane to a new heading by using the autopilot turn control, some means must be provided for locking or stopping the action of the rudder and

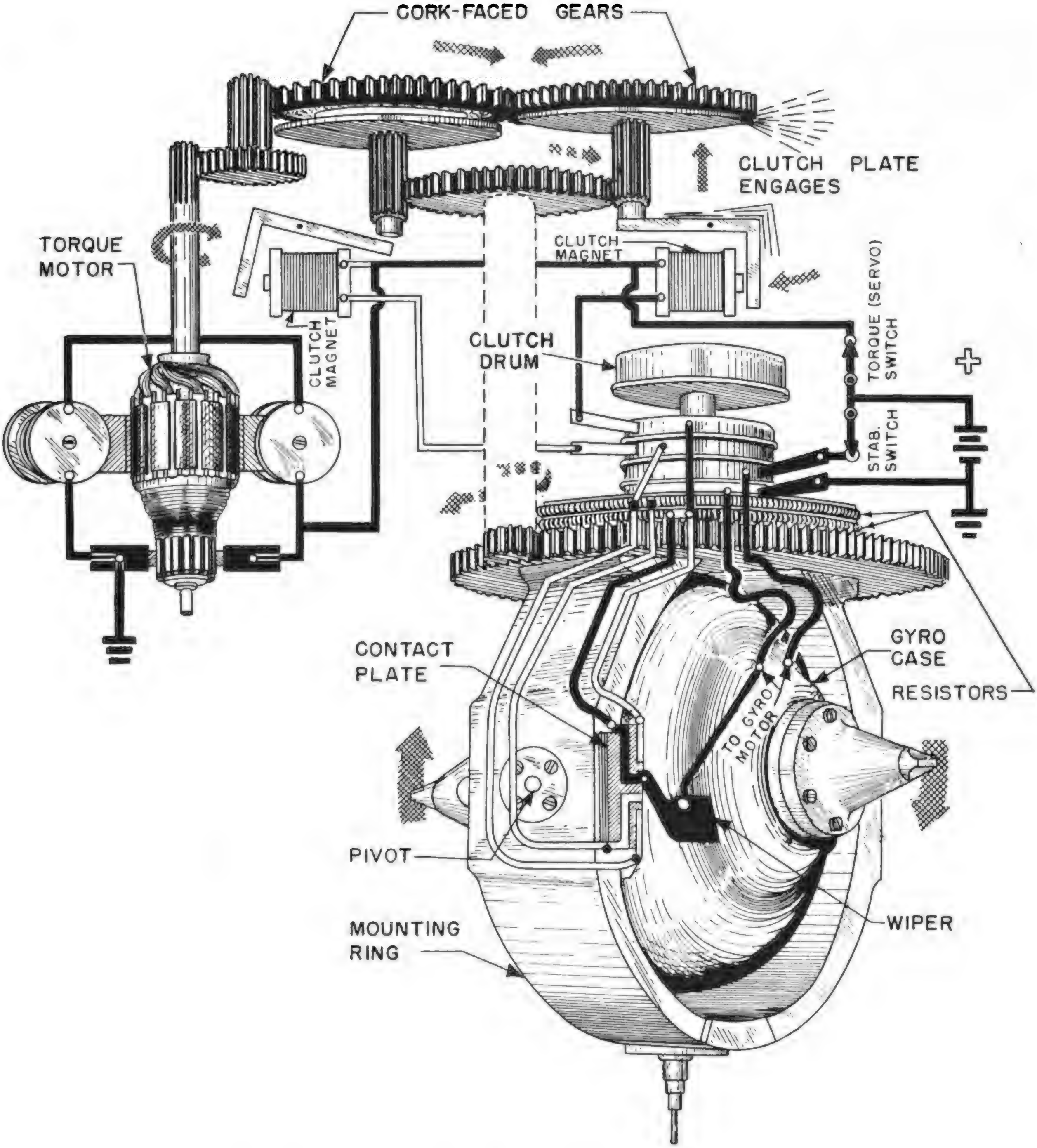


Figure 194. Action of torque motor in erecting directional stabilizer gyro.

aileron wipers in the directional panel. This is necessary because these wipers, moving across their pots as the airplane turns, would cancel out the signals coming from the turn control. The directional arm lock shown in figure 198, is used to clamp and hold the autopilot clutch arm (and with it, the wipers in the directional panel) fixed with the gyro case. It consists of a direct current solenoid which, when it is energized, pulls down and causes the clamping jaws to lock the extension of the autopilot clutch. When this occurs, the autopilot clutch, which is set at about 10 to 12 pounds inclusive, will slip on the

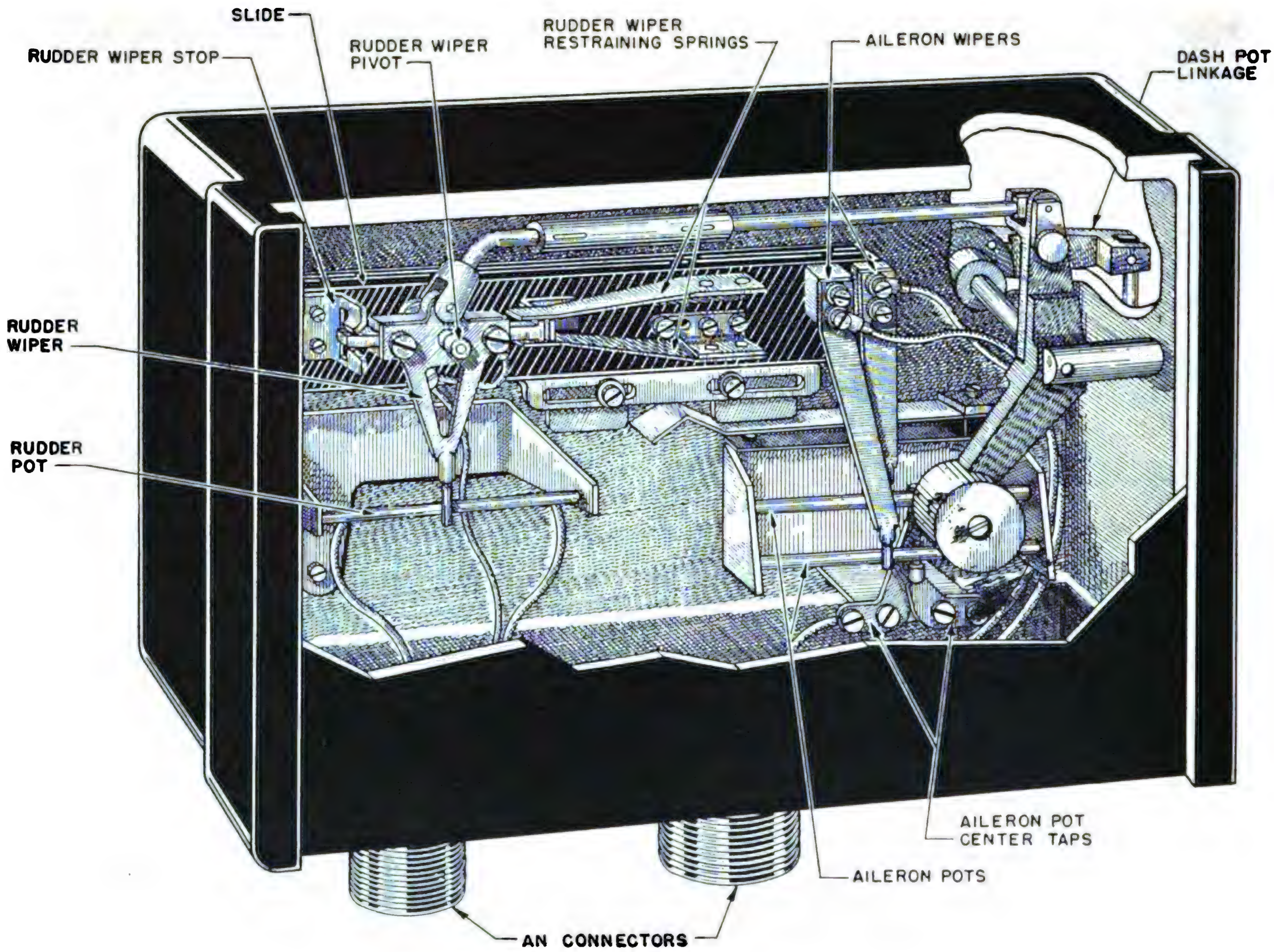


Figure 195. Interior of directional panel.

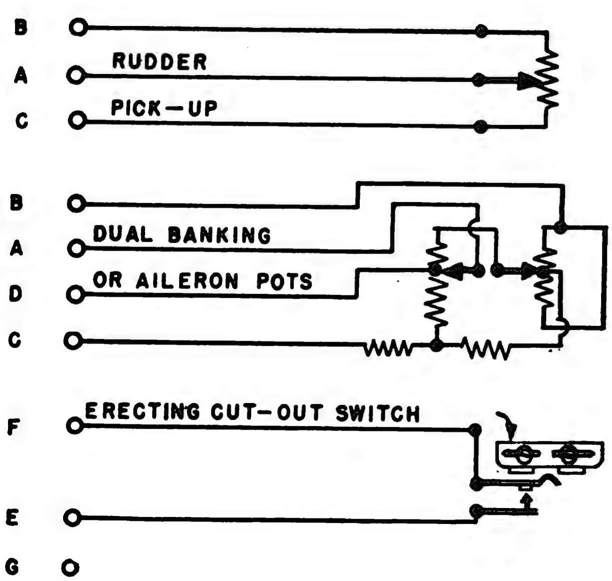


Figure 196. Wiring diagram of directional panel.

Figure 197. Pilot director indicator (PDI).

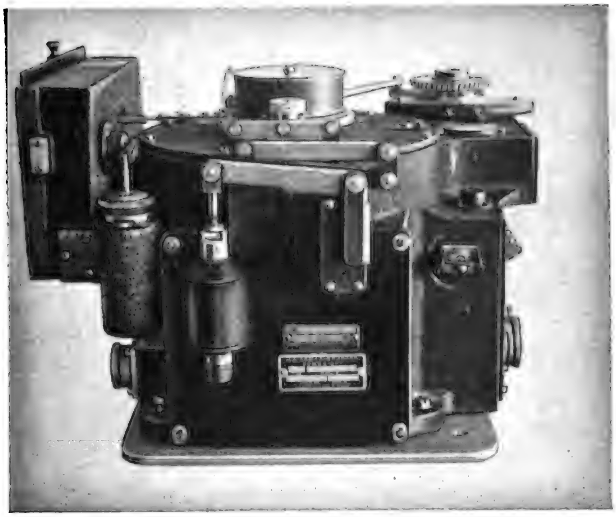


Figure 198. Directional stabilizer showing directional arm lock.

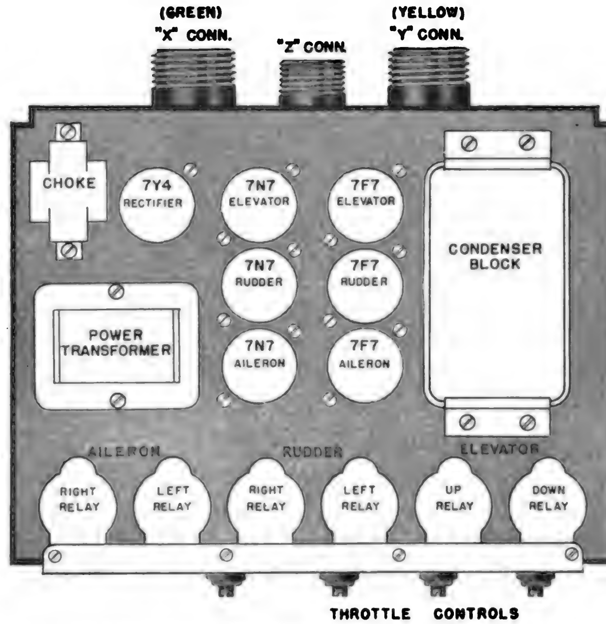
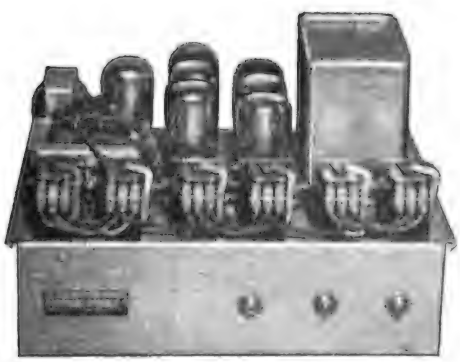


Figure 200. Arrangement of units in amplifier.

clutch drum. As soon as the turn control is moved back to neutral to stop the turn, the directional arm lock releases, and permits the autopilot clutch arm and the clutch arm to control the pots in the directional panel and thus keep the airplane on its new course. Operation of the directional arm lock is controlled automatically by the turn control knob on the autopilot control panel.

c. AMPLIFIER. (1) *Purpose.* The amplifier unit shown in figures 199①,②, and 200, is the central electrical unit of the C-1 autopilot. It performs two main functions. First, it amplifies, sorts and reroutes the incoming signals from the control bridges, distributing them so as to cause the servo units to operate in the desired directions. Second, it supplies a-c power for its own use and for the main bridge and control circuits. It also contains a d-c power section, which rectifies a part of the incoming a-c for use by the amplifier itself.

(2) *Description.* There are seven tubes in the amplifier unit: one 7Y4 rectifier which furnishes the direct current, and six other tubes which are arranged in three pairs. Each pair consists of one 7F7 dual purpose amplifier-control tube and one



① *Front view.*

② *Rear view.*
Figure 199. Amplifier unit.

7N7 discriminator tube. (See fig. 199①.) The tube circuits are arranged in this manner to provide three identical electrical channels, one each for aileron, rudder and elevator signals. (See fig. 201.) All connections between the amplifier and the rest of the system are made through the three color-coded AN connectors on the rear of the case.

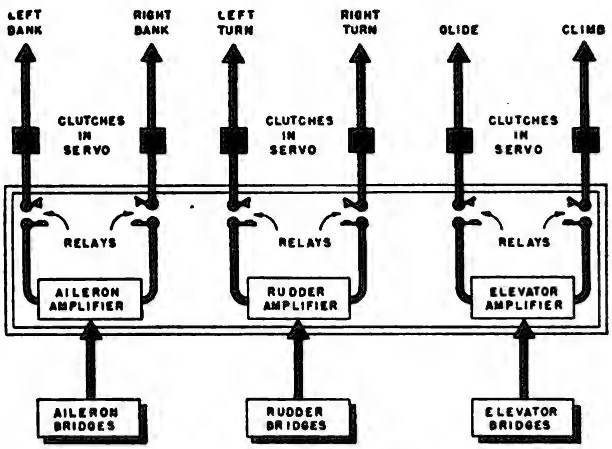


Figure 201. Amplifier control channels.

(3) *Operation.* As long as the bridges are balanced, no signal will be sent to the amplifier. If motion of the airplane should move one of the three main control pots, the bridge will become unbalanced, due to the unequal voltage drops now established across it. As a result of this, a signal will be sent to the first section of the amplifier-control tube. Here, the strength of the signal is built up. In the second section, the amplified signal is modified by three other voltages which are applied to the same tube. These three voltages are sensitivity voltage, the feedback voltage, and the throttling voltage. Their values are set by manually controlled adjustments of the autopilot. The first of these, the sensitivity voltage, determines how strong a signal must be in order to pass through the control stage. By adjusting this sensitivity voltage, the autopilot can be made to react to the very weak signals resulting from a slight deviation, or to only the much stronger signals due to a larger deviation. Feedback voltage adjusts the circuit of the control section to take care of the border line signals, that is, those so close to the sensitivity level that they would just barely pass on and would cause a hesitant, chattering action of the relays which control the servo units. These signals are picked up and amplified further until they are strong enough to close the relay firmly. The throttling voltage continuously modifies the amount of control that each signal impulse applies to the servo units. As a result, when the airplane begins to come back on course and the signal impulses become weaker, the amount of control applied will be decreased by allowing the servo to rotate for shorter and shorter periods of time. After being modified by these three control voltages, the signal goes on into the second tube of the channel, the 7N7 discriminator. This tube determines the direction of control called for by the signal, and directs the signal into the circuit which will cause the servo cable drum, for that channel, to rotate in the desired direction. Each of the servo units therefore has two control circuits, one for each direction of rotation. Each of these circuits contains a relay which is energized by the signal through the selective action of the discriminator. When one of the relays is energized, the servo cable drum turns and applies the correction to the control surface. As the airplane comes back on its course, the control applied by the relays must be decreased or the airplane will tend to overshoot. This is accomplished by a special circuit in the relays and by the throttling action of the amplifier control tube, which causes the relays and the servos to operate intermittently as the airplane responds to control. This on-off action of the relays and servo units is called "pecking." If the airplane deviates from its course by a large amount, the servo unit will run continuously for a short time and then, as the airplane begins to straighten out and less control is needed, the pecking action will begin. As the airplane approaches its course the pecks will become less frequent, stopping entirely when the "On-Course" position is reached and the circuit is balanced. The amount of servo cable drum rotation for each peck is adjustable and depends on the control response of the airplane in which the autopilot is installed. The main controls for the pecking action of the relays (the three throttling voltage controls) are located on the front of the amplifier unit. (See fig. 200.)

d. Servo Units. (1) *Purpose.* The three servo units provide the means by which the electrical signal impulses from the control bridges and converted into the actual motions of the control surfaces required to return the airplane to its course. The servo units operate the control surfaces through a set of servo cables which are attached to the main control cables.

(2) *Description.* Three identical servo units are used, one each for the aileron, rudder and elevator control system. (See fig. 202.) The servo unit itself may be divided into two main sections. The first of these contains a 1/20 horsepower d-c motor

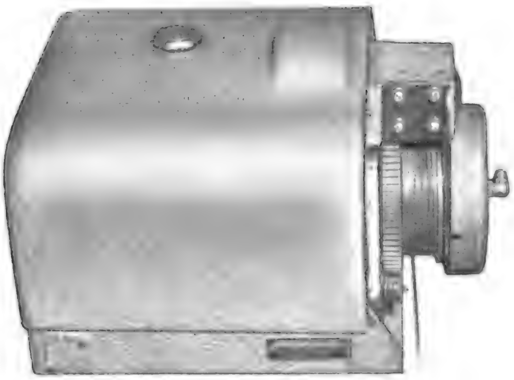
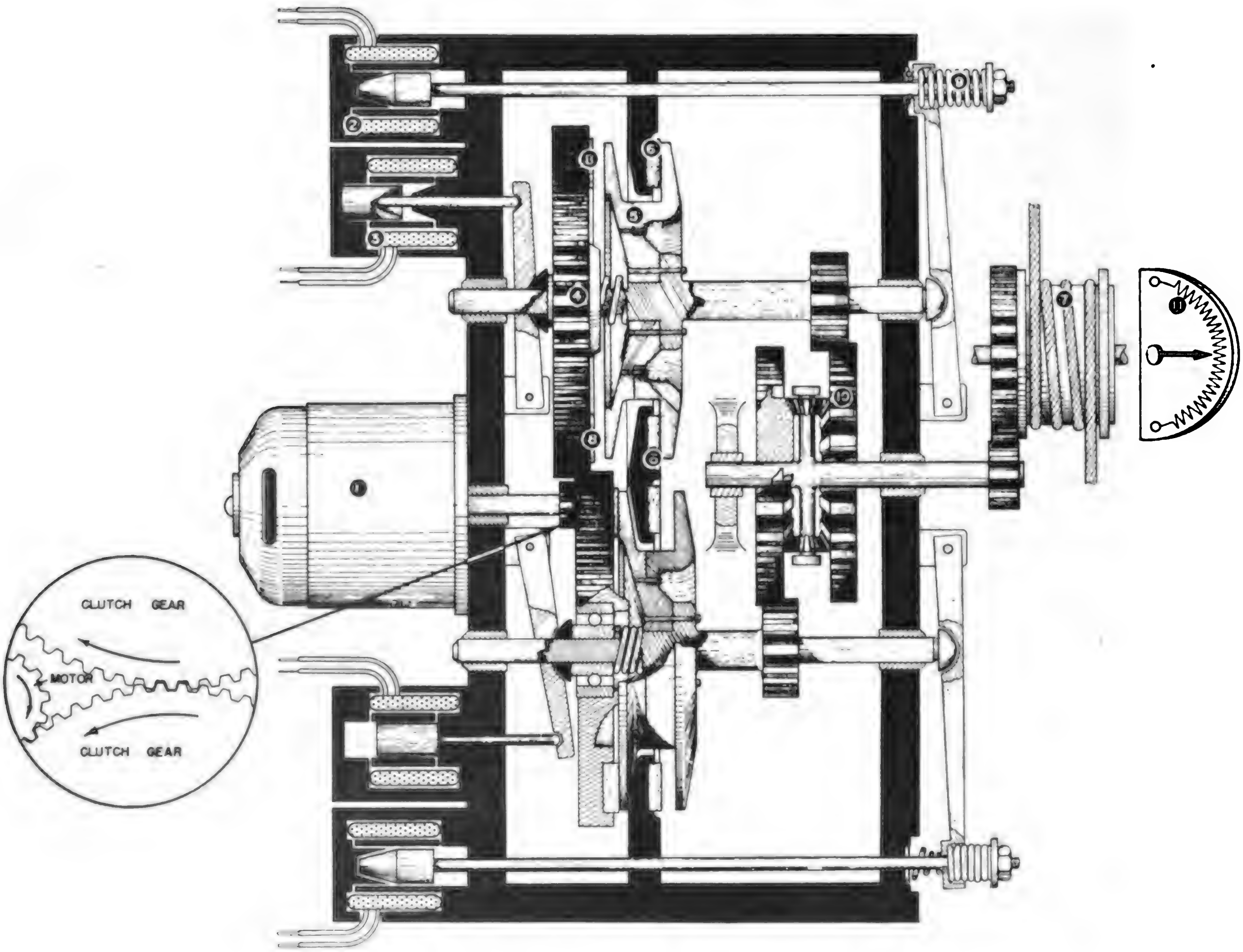


Figure 202. Servo unit.

which supplies the power for the servo unit. This motor is connected to the airplane's d-c supply, and runs continuously in one direction as long as the autopilot is operating. The second or main section of the servo unit is composed of two identical power transmission systems, one for each direction of rotation. (See fig. 203.) The action of each of these systems is controlled by a brake solenoid and an engaging solenoid.

(3) *Operation.* With the autopilot turned off, as shown in figure 204①, both solenoids will be inoperative. The clutch gear will therefore rotate, without any effect on the rest of the system. As the clutch and brake disk is not engaged, the cable drum will be free to turn and the pilot can fly the airplane manually. When the autopilot is turned on, the brake solenoids of both halves of the servo will be energized, causing the clutch and brake disks to be pressed against the cork brake rings mounted in



1. Motor.
2. Brake Solenoid.
3. Operating solenoid.
4. Clutch gear.
5. Clutch and break disc.
6. Fixed brake corks.
7. Cable drum.
8. Clutch gear corks.
9. Brake spring.
10. Differential gearing.
11. Servo balance pot.

Figure 203. Schematic drawing of servo unit.

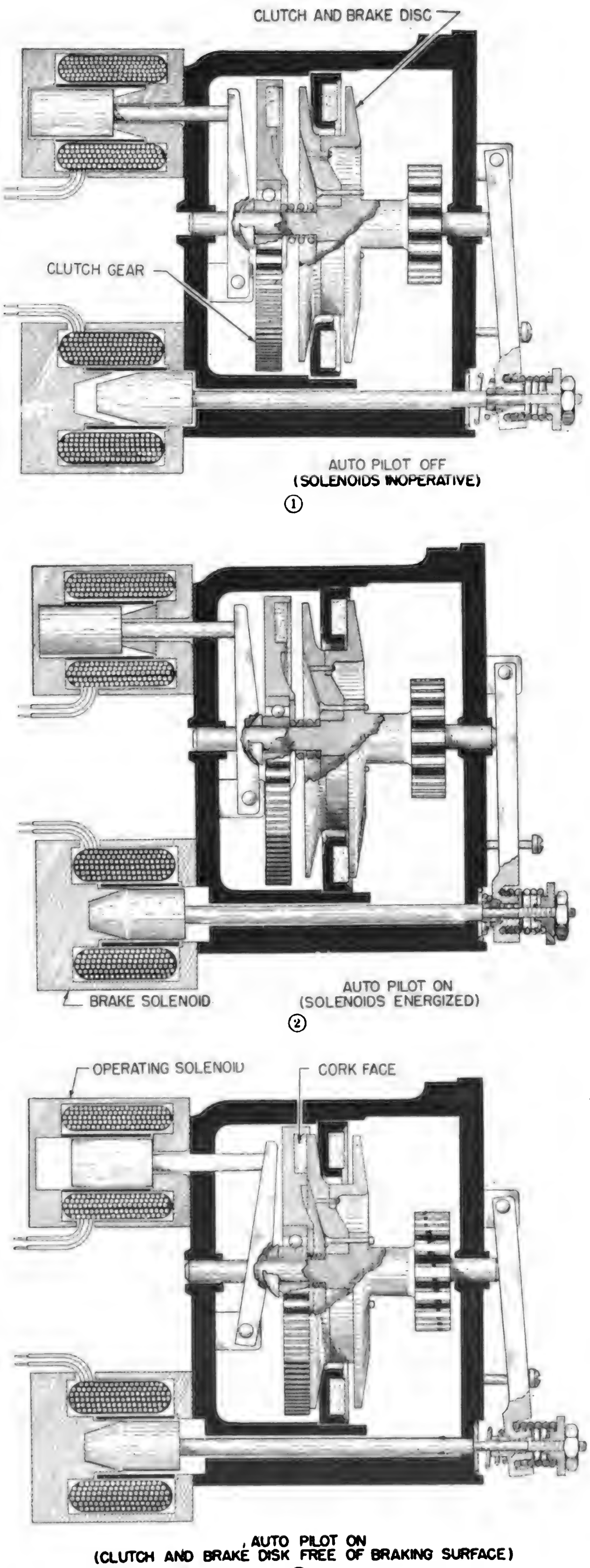


Figure 204. Operation of the servo unit.

the housing. (See fig. 204②.) As the clutch gear is not engaged, the servo cable drum will be locked in position, holding the control surfaces rigid as the autopilot takes over control of the airplane. These brake solenoids will be on as long as the autopilot is being used. Whenever the engaging solenoid is energized (by the closing of its relay in the amplifier) the cork face of the clutch gear will be pushed against the clutch and brake disk. This will move the clutch and brake disk to the right (against the pressure of the brake spring) and free it from the braking surface. (See fig. 204③). The disk will then rotate (in the same direction as the clutch gear) and drive the differential gear assembly which, in turn, drives the cable drum in the desired direction. Inasmuch as only one engaging solenoid at a time will be on, the other half of the system will remain locked. When the relay in the amplifier opens, the engaging solenoid will be cut-out. The brake spring will then reengage the clutch brake disk to its friction surface, locking the cable drum and the control surface in their new positions until further control is applied. In a friction-controlled system of this type, the servo is able to start and stop instantly, adapting its control exactly to the pecking action of the relays in the amplifier. The friction between the cork surfaces and the disks provides sufficient driving and holding force to move and hold the control surfaces under the most severe conditions likely to be encountered during flight. (In an emergency, the autopilot can be overpowered by applying enough force to the controls to cause the servo brakes to slip.)

(*a*) *Balance pots.* The balance pot for each of the three control bridge circuits is placed on the end of the cable drum (fig. 205) of each servo unit. This pot serves to diminish the strength of the corrective signals and rebalance the control circuit as the airplane comes back on course, and thus prevents over-control. The wiper of the pot is attached to the cable drum, while the pot winding is fastened to the servo housing. The signal picked up by the wiper of this pot is taken off by another wiper and a collector ring, eliminating the need for flexible pigtail leads.

(*b*) *Limit switches.* Inasmuch as the servo unit applies a considerable force to the control surfaces, some provision must be made to prevent the autopilot from driving these surfaces into their mechanical limits, which might cause considerable damage. This is done by attaching a cam-operated limit switch, shown in fig. 206, to the gearing that drives the cable drum. The cam of this switch will turn

Figure 205. Servo unit balance pot.

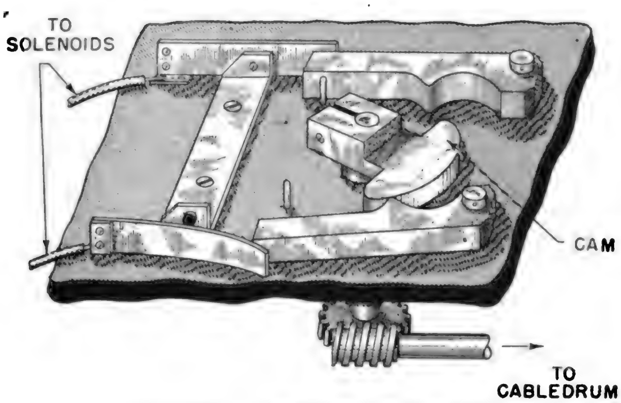


Figure 206. Servo unit limit switch.

in the same direction as the cable drum, and will open the circuit to the operating solenoid whenever the maximum allowable throw for the control surface has been reached. The contour of each limit switch cam is filed to suit the limits of control surface movement for each individual airplane. Should the servo unit be replaced, the cam must be removed and placed on the new unit. A schematic wiring diagram, showing the location of the limit switches in the servo unit circuit, is given in figure 207.

e. Autopilot Control Panel (ACP). (1) *Purpose.* This unit contains the switches and most of the adjustments necessary for the use and control of the C-1 autopilot. (See fig. 208.) It is normally located on the main instrument panel of the airplane, but may be placed at any convenient point in the cockpit. A number of the adjustments

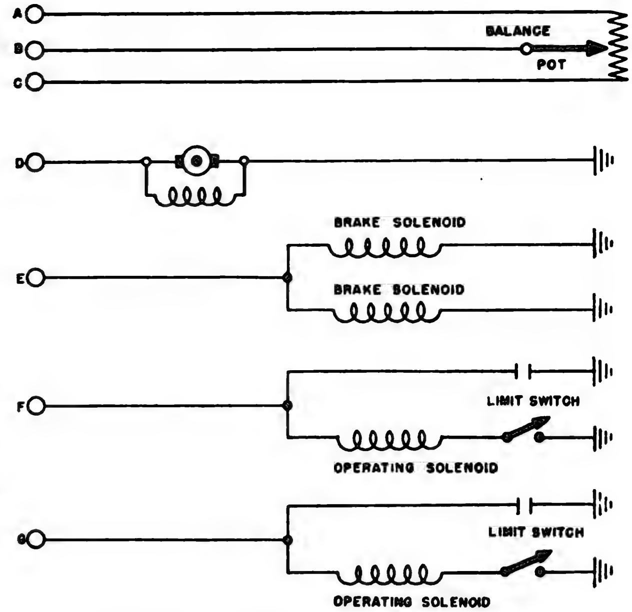


Figure 207. Wiring diagram of servo unit.

Figure 208. Automatic pilot control panel (ACP).

are not changed after they have once been set. On later models, a cover has been added to prevent any unnecessary tampering with these settings.

(2) *Description.* The autopilot control panel may be divided into the six sections described below.

(*a*) *Switches.* Along the left hand side of the panel are arranged the six switches which control the current supplies to the autopilot system. The first (master) and fifth (stab) switches, which are linked together by a bar, control the current supplied to the gyro motors, the servo motors, and the

rotary inverter. They are connected in this manner so that both gyros can be turned on before the autopilot is engaged in order to allow them sufficient time to reach their correct operating speeds. The switches marked AIL, RUD, and ELEV are engaging switches for these controls. Whenever one of these switches is thrown, the brakes of the servo which operates that control will be engaged, and the control will be locked. Any or all of the switches may be turned on, depending on the amount of control it is desired to give to the autopilot. If one of the controls should become inoperative under autopilot action, it may be returned to manual control by turning its switch to the "Off" position, which will release the brakes and place the servo in neutral. The last of the six switches, marked SERVO-PDI, turns on the torque motor which stabilizes the gyro in the directional stabilizer. It also supplies current to the pot winding of the PDI wiper. In an emergency, the entire autopilot may be disengaged by snapping the bar to the left. This will turn off all switches simultaneously.

(*b*) *Centering controls.* The three knobs near the top of the panel are the centering knobs. They control three sets of dual potentiometers, one of which is connected into each side of the three main control circuits. When these potentiometers are used to adjust the action of the autopilot, they shift the electrical balance point of the main bridge circuits so that (with the autopilot engaged) the circuits can be balanced and the airplane can be made to fly courses other than straight, level flight. The centering knobs are also used to shift the electrical balance points of the bridge circuits until they are at the same points on the pot windings as the wipers, which are positioned by the physical attitude of the airplane. If this is not done before the autopilot is engaged, the autopilot will immediately move the control surfaces, seeking to drive the servo balance pots to a point where they will rebalance the circuit. As a result, the attitude of the airplane may be suddenly and violently changed. The centering knobs should be used to make only *minor* adjustments in the trim of the airplane during flight.

(*c*) *Telltale lights.* There are six telltale lights located across the top of the autopilot control panel, one for each direction of movement about each of the three axes. These lights give a visual indication of the amount and direction of control being applied through each of the three control channels. They also serve to show when the bridge circuits are balanced as the centering knobs are turned to trim the autopilot with the airplane before engaging the autopilot. When any bridge circuit is balanced, both lights for that channel will be out. When a servo is engaged to rotate in either direction, the corresponding light will go on. Since the lights are in the same circuits as the operating solenoids of the servo unit, and are controlled by the relays in the amplifier, they will show the "pecking" action of the servos. If one of the bridge circuits is heavily unbalanced, due to a large "off course" movement of the airplane the servo will at first run continuously, and the corresponding telltale light will burn steadily. As the airplane begins to come back on course, and the pecking action begins, the light will blink, first rapidly and then more slowly as the balance point is approached. The light will go out when the circuit is balanced. With the autopilot engaged and the airplane flying straight and level, all lights will be out, and will come on only momentarily when the servos drive in control to restore the airplane to its course, or when the centering knobs are used. The intensity of the lights may be adjusted by means of the small knob located to the right of the elevator lights.

(*d*) *Ratio and sensitivity controls.* These two sets of knobs provide the pilot with a means of adjusting the performance of the autopilot so that it will give the best possible results when it flies the airplane under automatic control. The first of the adjustments controls the sensitivity voltage, which is applied to the incoming signals in the amplifier-control tube of the amplifier unit. Normally, the sensitivity controls are set in the halfway or middle position, which is the correct setting for all ordinary flight conditions. In turbulent weather, the sensitivity should be decreased, to allow the airplane more leeway and permit it to "ride" the weather. Correspondingly, in smooth calm air, the sensitivity may be increased. The sensitivity settings do not control the speed of reaction of the autopilot; they merely establish electrical limits which must be exceeded before a correction will be put in. The ratio controls, which are located directly below the sensitivity knobs on the autopilot control panel, are used to adjust the amount of control surface movement which the autopilot will apply in order to correct a given deviation off course. In this way, they control the speed with which the autopilot will return the airplane to its course. Decreasing the ratio setting will cause the autopilot to react more slowly, while increasing the setting will cause faster corrective action. Once set for a particular airplane, the ratio setting will seldom require further adjustment.

(*e*) *Turn control (TC).* The turn control knob is located in the upper left-hand corner of the auto-

Figure 209. Turn control.

pilot control panel. (See fig. 209.) It is used to set the airplane into automatically-coordinated, banked turns while it is flying under autipilot control. Turning the knob will produce a banked turn in the direction in which the knob is turned. The amount of bank will depend on how far the knob is turned. The length of time that the knob is held off its center position determines how far the airplane will turn. As the knob is recentered, the airplane will level out and resume straight, level flight. Besides introducing the necessary turn signals, the turn control also engages the directional arm lock, and thus prevents the action of the directional stabilizer gyro from canceling out the turn signals as fast as they are set in. This is necessary because the turn control itself is nothing more than a manually operated pot sending its signal into the same aileron and rudder bridge circuits as those used by the pots in the gyros. The erection cut out in the VFG is also engaged at the same time as the turn control, to prevent the VFG from moving away from the vertical during a turn. Turns of up to 40° bank may be obtained with the turn control. A spring loaded warning stop has been placed inside the turn control unit at 30° right and left turn. The pilot can override this stop and set in additional turn up to 40° if he so desires. A similar detent position or stop is also placed a few degrees right and left of the center index mark, to warn the pilot that he must stop at these points and allow the airplane to level out before centering the turn control. This must be done because, as the turn control is returned to its center position, it will release the erection cut-out and the directional arm lock. If this occurs before the airplane is leveled out, the gyros will take over control of the airplane too soon, and will cause it to take an incorrect flight attitude. In some installations, a duplicate turn control is provided for the bombardier. Whenever he desires to use this control, the transfer knob in the lower left hand corner of the panel is turned from Pilot to Second Station. The indicator light next to it will be On whenever the bombardier has control. The relative amount of turn-and-bank that will be obtained when the turn control knob is used is determined by the two small screw driver adjustments "A" and "R", located just below and on each side of the rudder sensitivity knob. They are the turn control trimmers, and their values are set so that as the turn control knob is moved against the 30° stop, the airplane will go into a 30° banked turn.

(*f*) *Turn compensation.* The last three knobs on the bottom of the autopilot control panel are the turn compensation controls. They are used to introduce the correct amounts of control into each of the three channels so that when the bombardier moves the autopilot clutch arm, he will obtain coordinated turns of up to 18° bank in either direction. The aileron knob adjusts the strength of the signal from the aileron pots in the directional panel. The rudder knob and the elevator knob similarly adjust the strength of the signals from the rudder pot and the up-elevator pot. These three turn compensation trimmers are correctly set when a full displacement of the autopilot clutch arm will produce an 18° banker turn without slip, skid, or loss of altitude.

(3) *Operation.* Only a few of the adjustments on the autopilot control panel are actually used in flying the airplane under autopilot control. The two main power switches are first turned on, after which, the autopilot is trimmed up with the centering knobs and telltale lights. The servos are then engaged by turning their switches on individually. The sensitivity, ratio, turn compensation and turn control trimmer settings are seldom disturbed, once they have been adjusted. All changes in course are made by using the turn control. If the station transfer switch is thrown, the bombardier may then direct the heading of the airplane. The autopilot may be turned off by throwing the switch bar to the left.

f. Formation Stick. (1) *Purpose.* The purpose of this unit is to allow the pilot or copilot to control the flight of the airplane through the autopilot. The stick is manipulated in much the same manner as the conventional control stick.

(2) *Description.* Two control sticks are provided—one to the left of the pilot and the other to the right of the copilot. Each has a pistol grip handle which can be moved backward and forward and

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from side to side. A push button switch is located at the top of each stick. When the button on either stick is depressed, that stick takes over control. If both buttons are depressed simultaneously, the pilot's stick will have control. A set of gears and a friction brake are located at the bottom of each stick. They function to prevent rapid movement of the stick. Release switches, a J-box, and a function selector switch are used in conjunction with the formation stick. The four positions of the function selector switch are: On Servo Boost, Off, On, and On Elev. Only. Figure 210 shows the relationship of these units to the autopilot J-box and control panel. The formation stick J-Box contains four blocks of 14 terminals each. (See fig. 211.) It also contains four relays, a delay switch, a transformer, two centering potentiometers, and eleven resistors.

(3) *Operation.* With the function selector switch in the "Off" position, no action is obtained from the formation stick and the autopilot controls the airplane in the ordinary manner. All control by the pilot must be made through the autopilot control panel. When the selector switch is in any position other than "Off," movement of the stick will set in signals as explained below.

(*a*) With the selector switch in the "On" position, the airplane, under autopilot control will respond to movement of the formation stick. Movement of the stick toward the rear moves the elevator up and the airplane noses up. Forward movement of the stick moves the elevator down and the airplane noses down. Movement of the stick to the right moves the ailerons and the rudder, so that the airplane makes a coordinated right turn. Motion of the stick to the left will give a coordinated left turn. Wash-out signal is obtained from the gyro wipers in each case, so that as the stick is moved: the control surfaces moves, the airplane responds, the signal

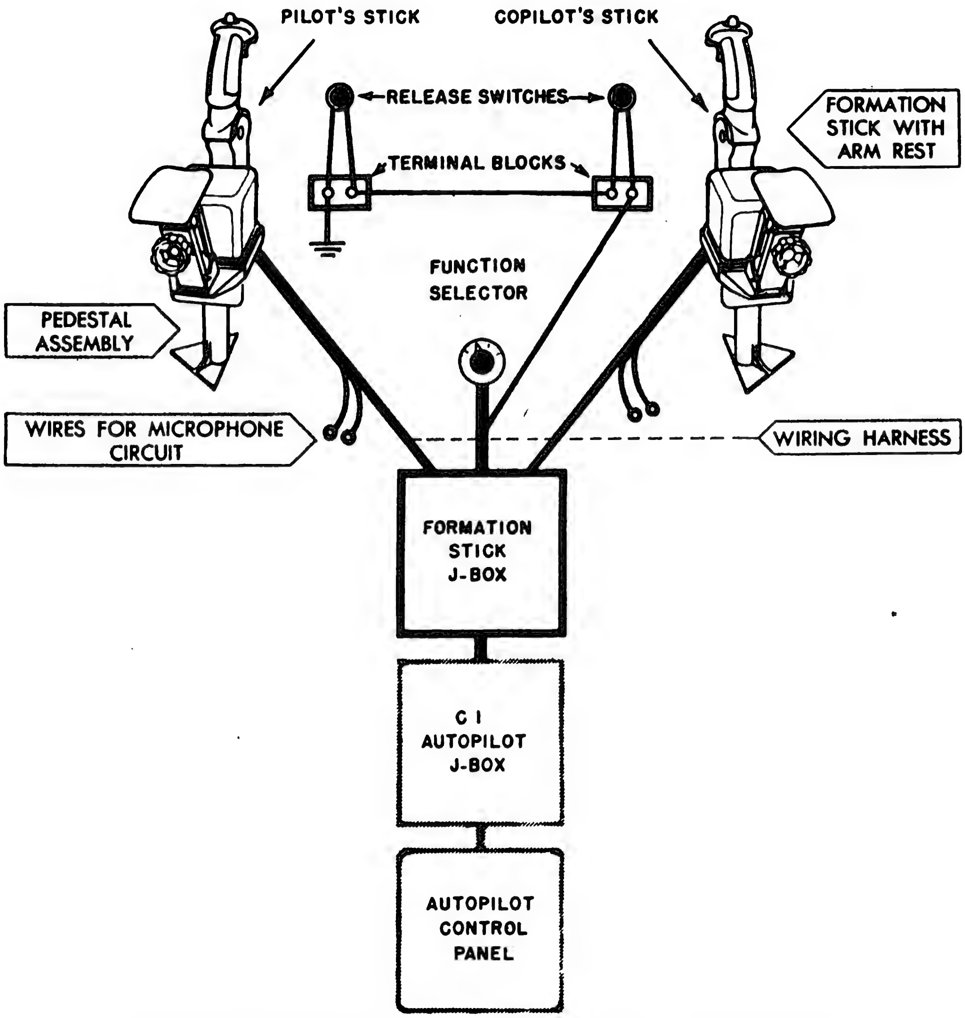


Figure 210. Relationship of formation-stick units to automatic pilot.

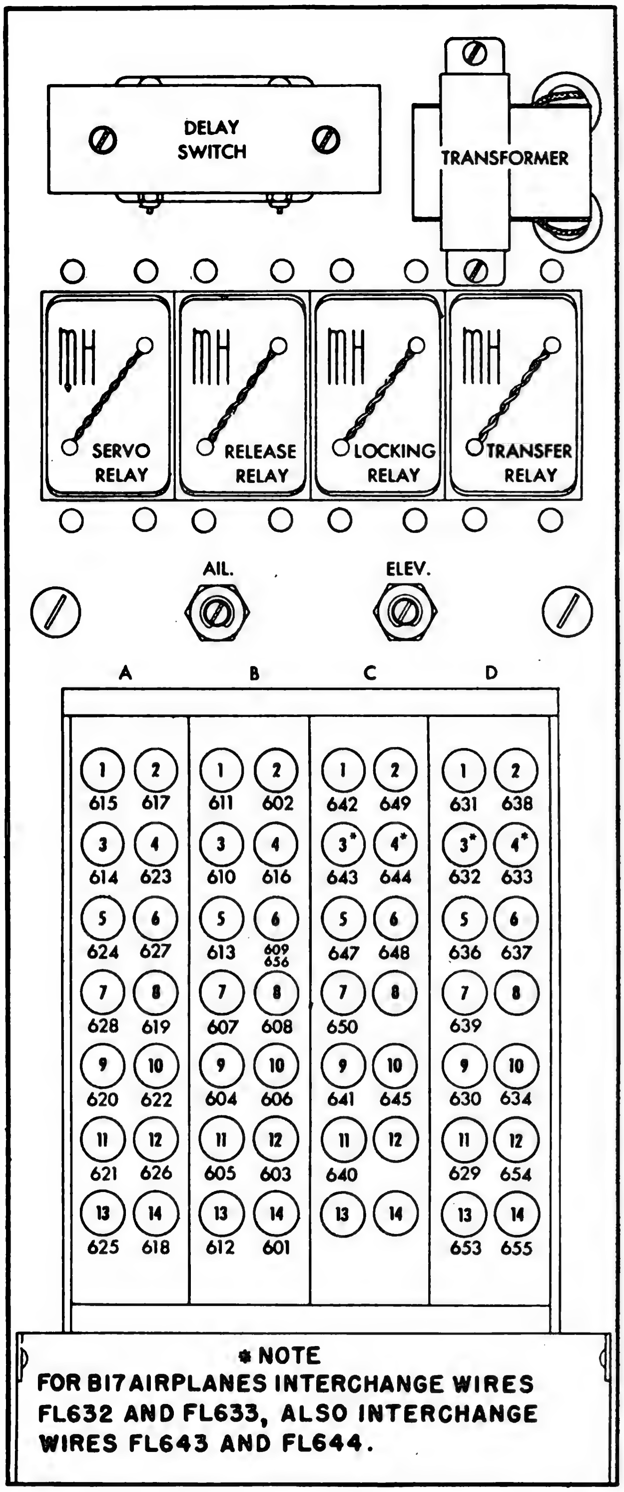


Figure 211. Formation-stick junction box.

is washed out, the control surface comes back to neutral, and the airplane remains in its new flight attitude.

(*b*) With the selector switch in "Elevator Only" position, only the elevators respond to movement of the Formation Stick. Turns can be set in from the turn control or directional stabilizer in the ordinary manner. The elevator control, which the pilot (or copilot) obtains in this manner, is a great deal more sensitive than that which can be obtained from elevator centering. This is especially useful on bombing missions, where it results in increased accuracy.

(c) With the selector switch in "On Servo Boost" position, the gyro circuits (aileron, elevator and skid pots) are shorted out. Hence, motion of the Formation Stick now results in a signal to the servo which cannot be washed out. Motion of the stick forward, for instance, will result in the airplane nosing down. Since there is no wash-out signal, when the forward movement of the stick is stopped, it merely stops further movement of the elevator. Since the gyro circuit is shorted out, no signal is put in to move the elevator until the stick is put back to neutral. Therefore, the airplane will keep increasing its angle of dive as long as the stick is held steady in an unneutral position. With the selector switch in this "On Servo Boost" position, no rudder action is obtained. Sidewise motion of the stick merely gives bank. Turn can be set in as normally, from the turn control and directional panel. Thus, motion of the Formation Stick from side to side permits slipping or skidding turns (which are sometimes necessary in formation flying) to be made. Effectively, this means that the pilot or copilot can now control the airplane in exactly the same manner as he could manually, except that the physical effort necessary is now obtained from the servo unit involved, rather than from the pilot's muscles.

g. JUNCTION BOX (J-BOX). (1) *Purpose.* The electrical junction box has two main purposes. It provides a centrally located point in the system through which all the units are interconnected. Also, since all the circuits of the pilot may be reached in the junction box, it provides a convenient point at which trouble shooting of the autopilot can be done.

(2) *Description.* The interior of the junction box contains seven, molded, terminal blocks, each with ten numbered terminals. (See fig. 212.) Each block has an identifying metal tag fastened to it. With this system, all wiring in the junction box can be coded with a number and a letter, so that any particular wire or circuit can be located easily for testing purposes. A listing of all wire and terminal numbers is provided inside the cover of the junction box.

h. ROTARY INVERTER. (1) *Purpose.* Since the C-1 autopilot requires a 19-volt, 105-cycle source of alternating current, the normal 26-volt, 400-cycle

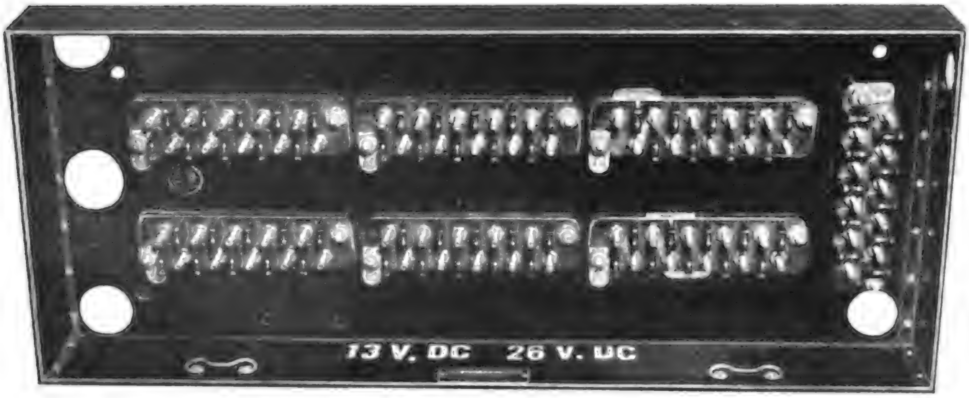


Figure 212. Junction box.

supply available on the airplane cannot be used. Instead, a special rotary inverter is provided to supply this current. It is mounted with the other units of the autopilot, and is connected to the airplane's d-c supply.

(2) *Description.* The inverter consists of a combination d-c motor and a-c generator, with both armatures wound on the same shaft. Direct current brushes are provided to energize the d-c motor field and armature, and a set of slip rings and brushes is provided to pick up the alternating current generated by the a-c windings. A filter system is included to reduce any radio interference caused by the inverter.

(3) *Operation.* The inverter is connected to the d-c supply of the airplane. To put the inverter into operation, it is only necessary to throw the master switch on the autopilot control panel to the "On" position. It requires no adjustments during normal operation.

73. How Autopilot Corrects Deviations

a. TRACING A SIGNAL THROUGH THE AUTOPILOT. Figure 213 shows the path taken by a corrective signal through the units of the autopilot system. The signal, resulting from an "off course" displacement of the airplane, originates in the gyro pot. It is picked up by the wiper, and goes first to the amplifier-control tube, where its strength is built up. Here the signal is also modified by the three control voltages. It goes next into the discriminator tube, which directs it to the proper servo control relay. The relay will then close the circuit of one operating solenoid in the servo unit, releasing the brake and allowing the cable drum to turn in the desired direction. As the drum turns, the servo balance pot

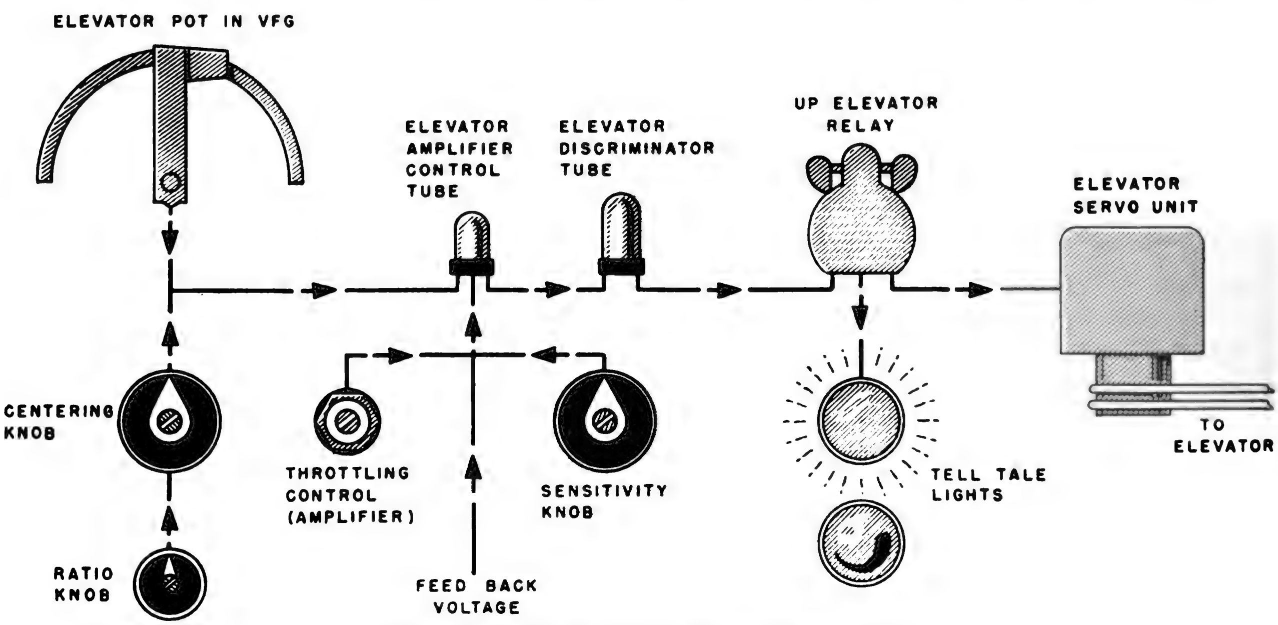


Figure 213. Path of a signal through the autopilot.

wiper (which is mounted on the drum) is turned. When the wiper has been displaced the same amount as the gyro pot, the circuit will be balanced and all control action will stop. Although the system shown is that of an elevator channel, the aileron and rudder channels operate in the same manner.

b. ACTION OF AUTOPILOT. The parts of figure 214 show the action of the C-1 autopilot units in correcting a deviation of the airplane. Although the action shown takes place about the lateral or elevator axis, the control systems for the longitudinal and vertical axes are similarly arranged and operate in the same manner. For the sake of explanation, the corrective action has been broken down into a series of separate steps, while on the airplane, it actually takes place very rapidly in one continuous operation.

(1) When the airplane is in straight, level flight, both the elevator pot and the servo balance pots are centered and the circuit is balanced, with no signal being sent to the amplifier. The brake solenoids in the servo unit are energized, holding the control surface locked in the streamlined position.

(2) If the attitude of the airplane is suddenly changed, the elevator pot winding will be moved away from its neutral position with respect to the wiper, unbalancing the circuit and sending a signal through the amplifier to the servo unit. The servo unit now begins to move the control surface to restore the airplane to straight level flight.

(3) As soon as the control surface is moved

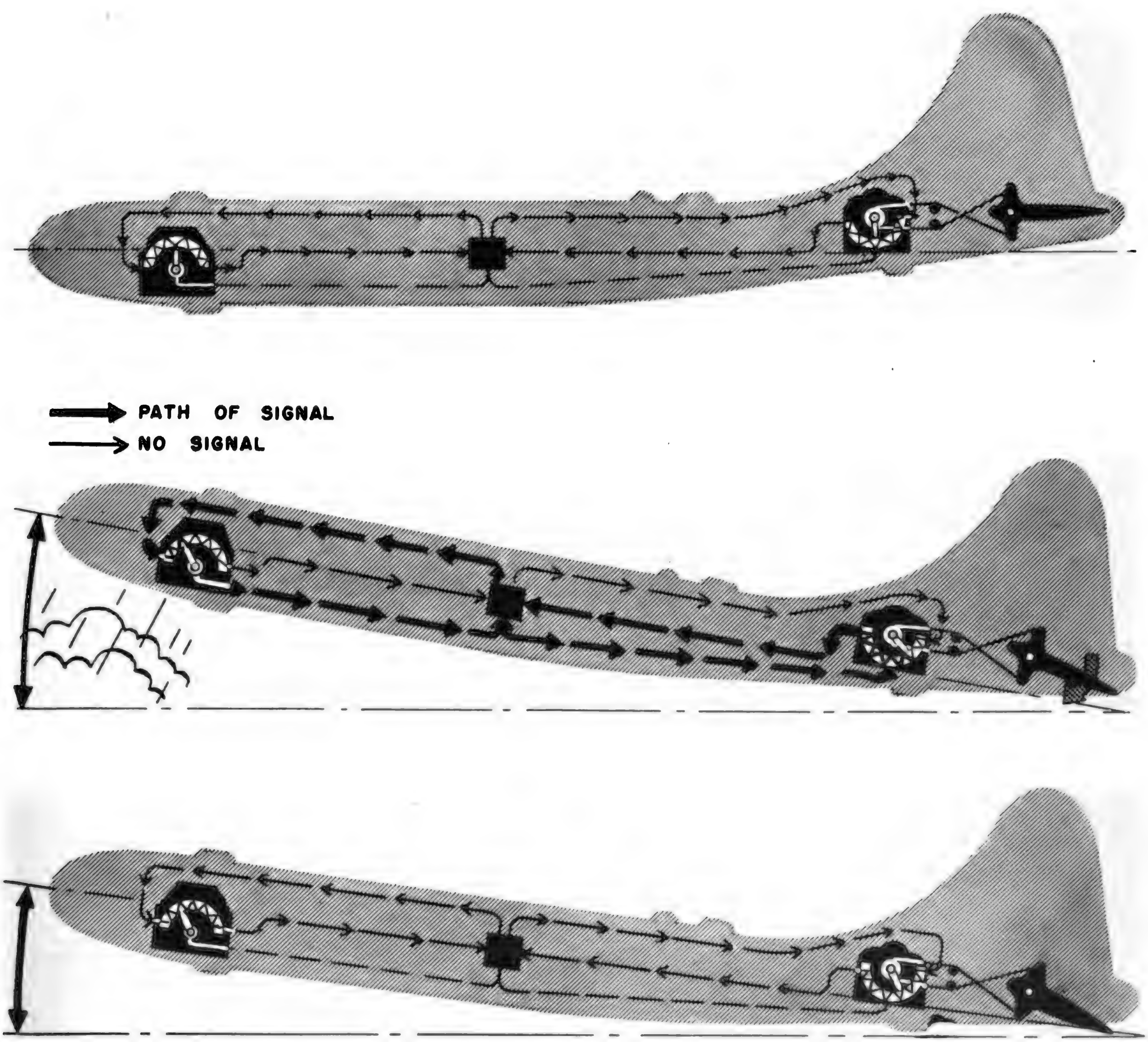


Figure 214. Action of the autopilot.

away from its streamline position, the airplane begins to level out. As it moves, the elevator pot winding starts to return to its neutral position. But since the servo balance pot is off center, at some intermediate position the two pots will be displaced the same amount, rebalancing the bridge circuit. This will stop rotation of the servo unit, and the control surface will again be locked.

(4) Although the control surface is no longer moving, it is still applying a correction, which rapidly returns the airplane to its level flight position. To prevent it from overshooting, reverse control is applied and the elevator begins to move to the streamlined position. This will take place because the motion of the airplane will again displace the elevator pot winding, unbalancing the bridge circuit again, but in the opposite direction.

(5) The reversed unit tends to streamline the control surface, canceling the correction as the airplane levels out. As the airplane gradually approaches its level flight position, the elevator pot winding moves closer to its neutral position, reducing the signal being sent to the servo unit. As a result, the motion of the airplane is slowed up, and it returns gradually and smoothly to its correct attitude.

(6) When the airplane is again flying straight and level, both pots are centered and the bridge circuit is balanced. The servo stops, and the servo brakes lock the control surface in the streamline position which keeps the airplane in level flight.

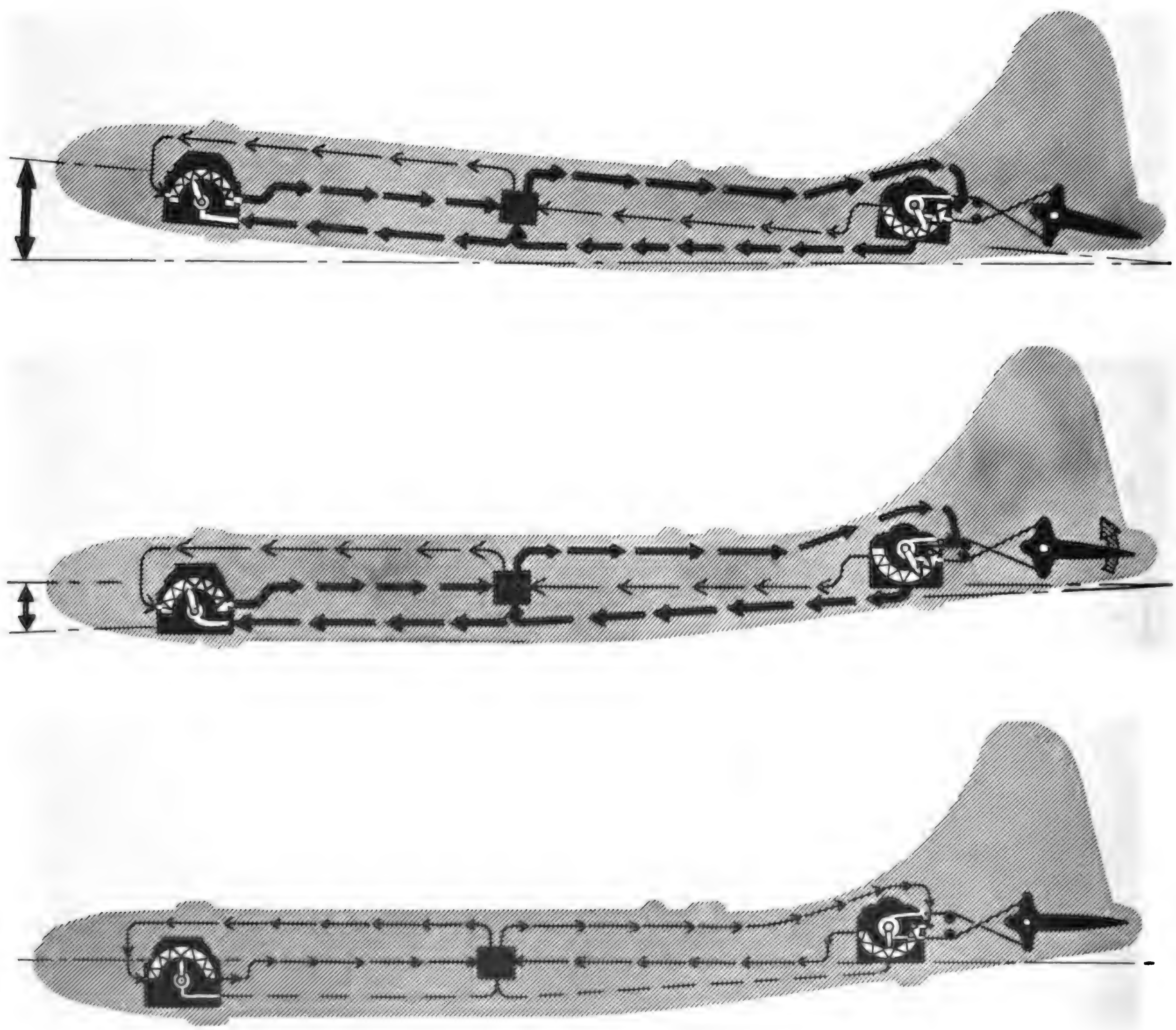


Figure 214—Continued.

74. Removal and Installation

a. General. Although the parts of the C-1 autopilot are ruggedly constructed and will last indefinitely under normal operating conditions, special care must be taken to prevent damage to the individual units during installation or removal. Authorized personnel *only* should perform these operations, using the proper tools and procedures. Precautions must be taken to avoid damaging the two gyro units, whenever they are handled while removed from their mounts, and their cases should never be opened except under conditions where it is impossible for dust or moisture to enter. Care must be exercised to prevent corrosion of the AN connectors in units removed from the airplane. Units installed in the airplane should not be used by crew personnel for steps, supports, seats or other purposes, as the equipment can be seriously damaged in this manner. All AN connectors must be correctly seated and firmly screwed into their sockets, and all ground leads must bond the unit to the airplane's structure. The actual location of the various units will depend on the type of airplane in which the autopilot is installed.

b. Vertical Flight Gyro. (1) *Location.* The flat base of this unit must be parallel to both the lateral and longitudinal axes of the airplane during normal flight conditions. The units should be installed with the triple potentiometer assembly on the roll axis and with the elevator pot on the right hand side. It is usually placed on the floor of the airplane, either in the cockpit or in the bombardier's compartment. Sufficient space must be left around the gyro to permit the easy removal of the AN connector, and on top, to permit the opening of the pot inspection doors and the removal of the cover or cover plate.

(2) *Mounting.* No special bracket or mounting assembly is provided. The unit is bolted directly to the supporting surface through the mounting holes at the bottom of the case. The four rubber grommets in the mounting holes should be used, as they provide the necessary shock mounting.

(3) *Connections.* All connections to the circuits in the vertical flight gyro are made through an AN connector on the back of the case. The plug should be correctly engaged with the socket, and the coupling ring screwed up tightly. This connector may be faced in any of five directions to make installation easier. The ground lead on the bottom of the case *must* be tightly connected to the metal structure of the airplane.

(4) *Preparation for use.* To prevent damage during handling and shipment, the VFG is shipped with a metal cover plate which locks the gyro spindle in place. Before the autopilot can be operated, this must be replaced with the transparent cover plate provided. A gasket should be used in seating the cover glass to prevent any dust or moisture from entering the case.

c. Directional Stabilizer. (1) *Location and position.* Because of its use in connection with the bombsight, the directional stabilizer is mounted in the forward end of the bombardier's compartment, slightly to the left of the bombardier's plateglass sighting panel, with the directional panel on the left and the directional arm lock to the rear. All electrical connections and switches are on the right hand side.

(2) *Mounting.* The mount provided for the directional stabilizer is a special antivibration mount. It consists of a heavy shock mounted plate, fastened to a lower plate which is attached to the base through a trunnion type joint. The whole assembly carrying the stabilizer can be tilted fore and aft to level the stabilizer. This is done by tilting the mount and observing the small bubble level on top of the stabilizer, directly below the circular PDI window. (See fig. 191.) A locking lever is provided to hold the leveling adjustment which should be set while the airplane is in level flight. Sufficient clearance must be provided around the stabilizer to permit installation and inspection of the directional panel and directional arm lock, as well as free access to the switches and AN connectors.

(3) Installing directional panel and directional arm lock. These units are usually shipped separately, and must be properly installed and adjusted before any attempt is made to use the stabilizer in the autopilot system. The directional panel mounts on the left hand side of the stabilizer. The rear of the directional panel case is fitted against the T-shaped mounting boss on the side of the stabilizer, and the four screws are tightened. The drive arm of the autopilot clutch should fit through the slot in the back of the case, engaging the recess in the directional panel slide. (See fig. 192.) The directional arm lock is installed on the rear of the stabilizer housing. The shipping plate (which holds the gyro motor rigid to prevent damage during handling) is removed and the arm lock panel is installed in its place. Slotted mounting screw holes are provided so that it can be moved up or down slightly until the tongue on the autopilot clutch arm does not bind the locking jaws.

(4) *Connections.* The electrical connections to the stabilizer circuits are made through three AN

connectors, two located to the rear and at the bottom of the right hand side of the stabilizer case, the other being a single wire connector on the directional arm lock panel. No ground lead is used on the directional stabilizer unit.

(5) *Preparation for use.* After all the AN connectors have been installed, and if an auxiliary power source is available, the stabilizer may be checked for operation by turning on the master switch on the autopilot control panel. After allowing 5 minutes for the gyros to warm up, the STAB-PDI switch and the rudder engaging switch on the ACP should be turned on. Turning the turn control knob just off its center position should cause the solenoid in the directional arm lock to clamp down so that the solenoid core just bottoms when the clamp is closed. This can be adjusted by screwing the core up or down as required. When the turn control is recentered, the spring should open the jaws of the lock so that they do not bind or touch the tongue of the autopilot clutch arm. The correct alignment of the directional panel may be checked by disengaging the autopilot clutch and rotating it until the PDI wiper (which may be seen through the circular PDI window) is centered. This setting should be locked by wedging the jaws of directional arm lock shut with a pencil. An ohmmeter placed between the center tap of the lower dual banking pot and its wiper should show a zero reading if the directional panel is correctly aligned. An eccentric adjustment is provided on the autopilot clutch arm to permit this alignment. The main rudder pot should also be checked to see that the resistance from the wiper to both ends of the pot is the same. The switches on the right hand side of the stabilizer are used in connection with the bombsight circuits, and should be kept in thee "Off" position when the stabilizer is working primarily as a unit of the C-1 autopilot.

d. Pilot Director Indicator. (1) *Location.* This unit is usually mounted directly on the main instrument panel in full view of the pilot. It may be placed on a suitable bracket if there is not sufficient room on the panel.

(2) *Connections.* The PDI is connected to its pot winding in the stabilizer through a two-prong AN connector on the back of the case. A mechanical-zero setting screw is provided for centering the pointer.

e. Amplifier. (1) *Location.* The autopilot amplifier has no specified location but in general, it should be placed as close to the junction box and the other units of autopilot as possible. It must have adequate ventilation, or it will be severely damaged due to excessive temperatures encountered during hot weather operation. It is important that the three AN sockets on the rear of the amplifier case be visible, as their code colors must be followed when installing the AN plugs. The amplifier should be mounted so that the side containing these AN sockets is to the rear, to permit removal of the chassis from the forward side.

(2) *Mounting.* The amplifier case is equipped with four single Lord type shock mounts, which are fastened directly to the supporting surface. It should be level, although its position is not critical.

(3) *Connections.* All connections are made to the amplifier through three AN connectors on the back of the case. As two of these three connectors are identical, and will fit in both sockets, it is extremely important that the colors of the plug and the socket be matched before the plug is inserted. The AN socket on the left side is coded yellow ("Y" on fig. 200) and connects the a-c bridge circuits. The connector on the right side is coded green ("X" on fig. 200) and connects the d-c circuits of the amplifier. It is obvious, therefore, that a great deal of damage could be done to the autopilot by interchanging these two connectors.

(4) *Preparation for use.* The amplifier is ready for use as soon as the AN plugs have been connected. There is no ground lead to the secured on the amplifier unit. The only adjustments are the three throttling voltage controls, which are preset at the factory and normally should not be changed. If these controls should need adjustment, the amplifier chassis must be removed and the settings checked on the C-1 autopilot amplifier test set by authorized service personnel.

f. Servo Units. (1) *Location and position.* The three identical servo units are located as close as possible to the control cable system of the surfaces they actuate. This is done to allow shorter runs of cable and thus eliminate the effects of temperature change on cable tension. It also makes it possible for the autopilot to fly the airplane if the remainder of the normal control system should be fouled or shot away. Normally, the rudder and elevator servos are located in the tail section of the airplane, while the aileron servo is located somewhere near the rear center of the wing, inside the main fuselage. The servo cable drum may face in any desired direction, but the mounting base of the servo unit should be level. Before installing any servo unit, check it to see that it has a yellow stripe on the housing just above the cable drum. This stripe indicates that the drum has been modified in ac-

cordance with Technical Orders. If this stripe is not present, the servo should be modified before installation.

(2) *Mounting.* The servo is mounted directly to a suitable bracket, platform, or support. No shock mounting is needed. The support used must be rigid and strong enough to withstand a cable pull of up to 500 pounds. Sufficient space must be allowed to permit easy removal of the servo dust cover for inspection and maintenance. As far as possible, the cable drum should face outward, to permit easy inspection of the servo balance pots. Although the base of the unit may be rotated around the cable drum axis to any desired position without harm, the face of the cable drum must be kept vertical and parallel to the servo cables at all times.

(3) *Connecting servo cables.* The servo units are connected into the main control cable system with ⅛-inch flexible steel cable and standard cable fittings. Guide pulleys should be used where necessary in routing the servo cables so that they will be, as nearly as possible, parallel to the main cables at the points of connection. To install the cables, the controls are locked in their level flight or neutral position, and the end dust cap and balance pot assembly are removed from the servo. The cable is not cut for attachment to the cable drum, but is looped and pushed in through a small slot in the side of the drum. (See fig. 215.) On the inside, it is looped around the hub of the drum and held in place by a cut-out cover plate that lays flat against the cable loop. Depending on the directions in which the two servo cables are to be run, they should be wound around the outside of the drum from 1¼ through 1⅜ turns. The slot in the cable drum should face away from the main cable. A turnbuckle is placed in each leg of the servo cable to adjust it to the correct tension. The cable tensions will vary with the type of the airplane, but will normally run about 10 pounds less than the main cable tensions. In no case should they exceed 100 pounds. These tensions should be set when atmospheric temperatures are reasonably normal (70° F.) and should be finally set only after the controls have been run through manually twenty or thirty times. This serves to flex and form the cables to their pulleys and drums, after which any unnecessary slack should be taken out.

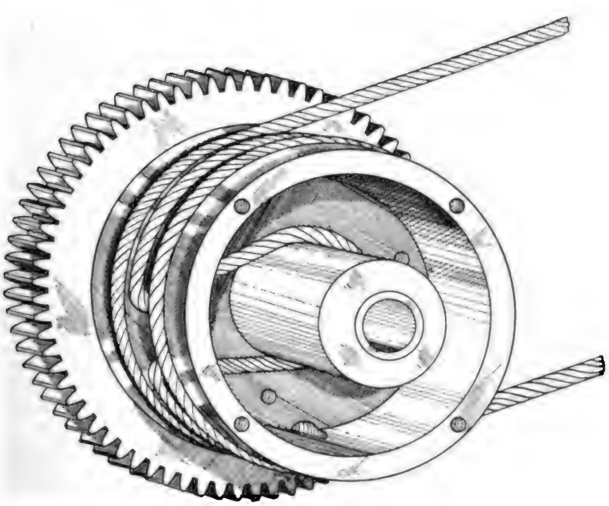


Figure 215. Method of connecting cable to servo drum.

(4) *Connections.* Connections are made to the servo through the AN connector provided on the back end of the case. This connector socket is similar to the one on the vertical flight gyro, and can be faced in five different directions to give the most convenient arrangement. It can also be mounted on either side as well as the back of the servo, if necessary. The servo units have no ground connections. If it is desired to reverse the servo's direction of rotation, this should be done by changing wires at the J-box and not at the servo unit.

(5) *Preparation for use.* With the airplane's manual controls locked in their level flight position, the wipers of the balance pots should be manually set to the mechanical center of their windings, and the cam of the limit switch should be centered. This is done by loosening the cam and turning it until it is equally spaced from both switch points. The rounded end of the cam should point toward the cable drum. The cam is then tightened. If the airplane requires that movement of the control surfaces be stopped at limits other than the ones at which the cam will open the switches, the lips of the cam must be filed down the correct amount. If the servo unit is ever replaced, this modified cam *must* be removed and placed on the new servo.

g. Autopilot Control Panel. (1) *Location and position.* The autopilot control panel should be placed at some point in the cockpit where it can be easily seen and reached by the pilot. In most recent installations, provision is made for a mounting directly on the main instrument panel, but the unit can be placed wherever sufficient mounting space is available. It may be inverted without affecting its operation in any way. Inasmuch as the turn control now used is built into the autopilot control panel, no provisions are made for mounting it separately.

(2) *Mounting.* To mount the autopilot control panel, the snap fasteners around the edge of the panel are loosened, and the control panel assembly is pulled

out of the case. The case is then bolted directly to the supporting surface. No shock mounting is used. Sufficient clearance must be left behind the panel for the connecting wires, and a rubber grommet should be placed in the hole in the rear of the case to protect them.

(3) *Connections.* Inside the case, the wires are fastened to numbered terminal blocks. The panel is then replaced in the case and the snap fasteners relocked. There is no external ground lead.

(4) *Preparation for use.* The autopilot control panel is ready for use as soon as it is installed and connected. A check should be made to see that all the control knobs work freely. The centering knobs should be checked to see that their pointers (which are driven through reduction gears) move correctly and freely as the knobs are turned.

h. JUNCTION BOX. The junction box is located as near the amplifier and other units of the autopilot as possible. Both ends of the box have holes cut in them to receive the wiring harness. When the box is mounted, the ends should be in a position to receive these harnesses. No shock mounting is used, and the box is mounted by bolting it directly to the support. Enough room should be allowed around the box to permit complete removal of the covers, as well as sufficient working space to reach and check all the terminals. This is important, since most of the checking and troubleshooting is done at this J-box.

i. FORMATION STICK JUNCTION BOX. This J-box is equipped with two mounting brackets. Four mounting bolt holes are necessary. CONSULT TECHNICAL ORDERS before connecting the wiring harness as it may be necessary to change some of the connections in both J-boxes.

j. ROTARY INVERTER. (1) *Location.* The inverter should be mounted near the junction box and amplifier units. Sufficient space should be allowed to permit removal of the end caps for servicing and inspecting the brushes. The unit should be well ventilated, as it will become quite warm during normal operation.

(2) *Mounting.* The inverter base (which contains the interference filter) is internally shock mounted, so it can be bolted directly to the airplane. The inverter should be mounted so that it will be level during normal flight.

(3) *Connections.* It is extremely important that the inverter ground cable be securely fastened to the metal structure of the airplane, and that a good electrical contact be obtained. The inverter is connected into the autopilot system and to the airplane's d-c supply through an AN connector on one side of the base.

k. WIRING. All wiring in the C-1 autopilot system will use stranded, insulated wire, the size depending on the load carried in the circuit. The exact wire sizes will be found in the installation wiring diagrams. All connections except those in the junction box are made with AN connectors; the junction box leads use crimped-on eye terminals. All autopilot wiring throughout the airplane is identified by the letters FL and a number which will be found on a paper sleeve around the end of each wire. The terminals in the junction box will have a number only. Only one nut should be used on each terminal in the junction box, regardless of the number of eyelets on the terminal. The autopilot cables should be supported with clips at frequent intervals (1 to 2 feet) as they are routed through the airplane, and protective grommets should be used where cables through bulkheads or compartments.

75. Operational Ground Check

a. WHEN ACCOMPLISHED. After the installation of the autopilot system has been completed, it is next given a thorough operational ground check. This inspection need not be repeated before each flight during which the autopilot will be used, but will be performed whenever any of the equipment is modified, altered or replaced, or whenever any work is done on the system.

b. PROCEDURE. Follow the procedure given in the applicable Technical Order. An auxiliary power source should be used to prevent too heavy a drain on the airplane's batteries. Make certain before leaving the airplane, that all switches are off and that the control surface locks are in place. If any defective units are found during this check, they should be removed and replaced with serviceable ones.

76. Operation

a. PREFLIGHT CHECK. After the ground check has been performed, and it has been determined that the autopilot operates satisfactorily, it is ready for use. The following preflight check should now be performed and should be repeated before every flight.

(1) Center turn control and disengage bombsight clutch on directional stabilizer.

(2) Turn on master (bar) switch on the ACP.

(3) Turn all control knobs on panel, except telltale light knob and station transfer knob, to "Pointers Up" position. Check for loose knobs or pointers.

(4) Ten minutes after the master (bar) switch was turned on, turn on Servo-PDI switch. In cold weather, allow 15 minutes for gyro to warm up.

(5) Disengage autopilot clutch on stabilizer, and center PDI wiper by moving back and forth until it is centered on its winding under the circular window. Reengage autopilot clutch. The directional arm lock should be pushed down to prevent PDI wiper from moving off center as autopilot clutch is reengaged.

(6) Operate all three controls manually through their full travel several times. This serves to clean off the pots and wipers. Watch the telltale lights as this is done. If they blink intermittently, the pot is dirty and should be cleaned.

(7) Turn on the three servo switches, one at a time. Each control surface should center itself in the streamlined position, and at the same time, the telltale lights should go out.

(8) Check the action of the servo by moving each of the three centering knobs back and forth while watching the controls. See that the control surfaces move in the correct direction as the knobs are turned.

(9) Disengage autopilot clutch and move it up against its stop in each direction. See that the rudder and ailerons move together to set in coordinated bombardier's turn.

(10) Recenter PDI wiper and reengage autopilot clutch.

(11) Rotate the turn control knob for a 30° turn in both directions. See that the ailerons and rudder controls move together to give the correct direction of turn.

(12) Recenter turn control, then recenter all control knobs. Turn off master switch. If at any time during a preflight check, it is found that any unit of the autopilot system does not operate correctly, the trouble should be investigated by performing the operational ground check referred to in paragraph 6*b*.

b. Flight Check. The procedure given below should be followed whenever it is desired to turn control of the airplane over to the autopilot.

(1) Turn control knobs to "Pointers Up" position. Center turn control. Turn station transfer switch to pilot. Telltale light control on.

(2) Throw the master switch bar to the right and, after waiting 10 minutes, turn on servo-PDI switch.

(3) Trim airplane manually for "straight and level" flight. Check flight indicator, and the turn-and-bank and rate-of-climb indicators.

(4) Have bombardier disengage bombsight clutch and autopilot clutch. Bombardier will now move autopilot clutch manually until PDI is centered. Bombardier holds adjustment by pushing down on directional arm lock. Autopilot is *not* engaged. If crew does not include a bombardier, leave autopilot clutch engaged and center PDI by turning airplane.

(5) With aileron centering knob, put-out both aileron telltale lights. Immediately turn on aileron switch. Adjust aileron centering to be sure wings are level.

(6) With rudder centering knob, put out both rudder telltale lights. Immediately turn on rudder switch. Bombardier will now release his pressure on the directional arm lock, and will engage the autopilot clutch. Adjust rudder centering knob to zero PDI, if necessary.

(7) With elevator centering knob, put out both elevator telltale lights. Immediately turn on elevator switch. Check rate of climb and flight indicator and adjust elevator centering knob, if necessary. The autopilot now has full control of the airplane.

(8) The sensitivity settings should be as high as possible, to give the greatest amount of flight stability. The correct setting is determined by advancing the sensitivty knobs until both telltale lights of the channel blink intermittently and the controls begin to vibrate or "chatter," and then backing off until the "chatter" stops. Ratio controls should be adjusted to provide quick recovery whenever a deviation occurs. However, if the ratios are set too high, the airplane will overshoot, then drop back, in a continuous slow back and forth movement or "hunt." The ratio controls are therefore adjusted to provide the best possible recovery rate without "hunt." Any hunting in each of the three axes can be checked by watching the wing tips, the horizon, and the PDI.

(9) The dashpot on the directional stabilizer must also be adjusted to provide the proper amount of resistance to the motion of the rudder wiper. If the dashpot is too tight, it will cause the rudder to hunt, and the PDI will oscillate. Too loose a setting will result in an irregular, unsteady movement of the PDI. An approximate setting may be made by screwing the dashpot adjustment all the way in and then unscrewing it one turn. The setting should then be locked.

(10) Finally, if it has not been done on a previous flight, the pilot's and bombardier's turn controls must be adjusted so that a fully coordinated banked

turn of the airplane will result where either one is used. To set the bombardier's control, the airplane is first trimmed for straight and level flight with the centering knobs. The bombardier should then disengage the autopilot clutch, and move it either right or left against the stop. This may be done by moving the autopilot clutch engaging knob, or by turning the bombardier's turn knob, if one is provided on the directional stabilizer. The aileron turn compensation knob on the bottom of the autopilot control panel is then adjusted until the flight indicator shows 18° bank. The rudder turn compensation knob is used to put in enough rudder to center the ball inclinometer, and the elevator turn compensation knob is set so that no loss of altitude will occur during the turn. When this has been done, the bombardier will re-engage the autopilot clutch, and the autopilot will then return the airplane to course and center the PDI. If the PDI overshoots or comes back very slowly, the aileron ratio should be correspondingly decreased or increased.

(11) To coordinate the pilot's turn control, the airplane is again leveled up with the centering knobs. The turn control knob is then moved off center in either direction until its pointer rests at the 30° detent at the edge of the shaded area. The screwdriver adjusted aileron turn control trimmer is then turned until the flight indicator shows 30° bank. Next, the rudder trimmer is adjusted to eliminate any skid, or until the ball inclinometer is centered. Loss of altitude will be prevented by the elevator correction which was set in when the bombardier's turn was coordinated. If any loss of altitude does occur, the elevator centering knob can be used to correct for it; but if this is done, the elevator centering knob must be readjusted when the airplane is again in straight level flight. In using the turn control, the knob must always be stopped at the "Zero Detent" position until the wings are level when coming out of a turn. It is then centered.

(12) The autopilot is now fully engaged and coordinated to control the flight of the airplane. Normally, during flight, the only controls on the autopilot control panel that will be used are the turn control and the centering knobs. Once the ratio, turn compensation and sensitivity controls have been correctly set, they will require only slight changes during future flights, and therefore should be left alone. To prevent tampering with the controls and changing these settings, recent autopilot control panel installations are provided with a cover plate for the lower half of the control panel.

77. Maintenance Inspections

a. Special Inspections. Although the C-1 autopilot will operate satisfactorily throughout a wide range of climatic conditions, special inspections are necessary (under certain extremes of temperature or humidity), to determine what effect these adverse conditions may be having on the autopilot equipment. These inspections, in addition to the regular maintenance inspections, are performed at the specified periods.

(1) *High altitude operation.* In common with other electrical equipment on the airplane, the d-c motors throughout the autopilot system will show abnormal brush wear whenever the autopilot is used in altitudes above 20,000 feet. As the check on this condition, all brushes in the autopilot units are inspected after each 10 hours of operation at or above the 20,000-foot level. The most positive indication of worn brushes will be the presence of fine carbon particles on the inside of the case. If these particles are present, the commutators should be cleaned and new brushes installed.

(2) *High humidity operation.* When operating the autopilot in areas where the humidity is high, difficulty may be encountered with corrosion on certain parts of the equipment. Care must be taken to see that all gaskets used are properly installed. All covers should be tightly fastened. The clutch surfaces of the directional stabilizer, which are cast iron, must be inspected and oiled daily. If operating in or near a salt water area, the copper eye terminals in the junction box must be inspected and oil lightly to prevent corrosion.

(3) *High temperature operation.* When operating in regions where the prevailing temperatures are high, special precautions must be taken to prevent damage to the amplifier unit. It must be given adequate ventilation at all times. If this is not done, the insulating wax in certain parts may melt, resulting in permanent damage to the unit. As the directional stabilizer is mounted in the transparent nose of the airplane where the direct rays of the sun may overheat it, it should, if possible, be removed to some cooler place whenever it is not in use. It must be checked frequently to see that heat has not thinned out the oil in its bearings, and should be lubricated as often as required to keep the proper oil film in these bearings.

(4) *Cold weather operation.* At temperatures below —12° C. (10° F.) special preheating of the autopilot units is required to insure correct operation. This may be done by turning on the perma-

nently installed electrical heating covers. A heater may be inmprovised by using canvas, blankets or other substitutes, and a flexible tube of the aircraft's heating system. In any case, the equipment should be heated for at least 1 hour before take-off, and heat should be left on continuously during flight. When the electrical heating covers are used on the ground, an external power supply should be used to prevent excessive drain on the airplane's batteries.

b. PERIODIC INSPECTIONS. (1) *Twenty-five hour inspection.* This inspection is primarily a cleaning inspection to remove any oil, grease, or dirt that may have accumulated on the pots, the friction clutch surfaces and the commutators of the various motors. The only authorized cleaning solvents are white gasoline for the pots and alcohol for the friction surfaces. No solvents should be used in cleaning the commutators. On this inspection, a check is also made to see that there are no defective or broken units, and all moving parts operate correctly and freely without binding.

(2) *50-hour inspection.* The 50-hour inspection is performed after the second 25-hour inspection, and is the main lubrication period for the C-1 autopilot equipment. All bearings, bearing surfaces and mechanical joints are lubricated at this inspection period, and the tensions and clearances of the various units are checked and adjusted. The only authorized lubricants are Bombsight L (Light) oil and Bombsight H (Heavy) oil. When performing any lubrication on equipment of this type, it is well to remember that all the oil that is needed is a thin film, and that excess oil can do a great deal of damage by picking up dust and dirt. Care must be taken to see that oil is not allowed to get on the cork friction surfaces in any of the units.

(3) *100-hour inspection.* At the 100-hour inspection, the 25- and 50-hour inspections, are repeated. The autopilot is then run through the complete operational ground check given in paragraph 6*b*.

(4) *200-hour inspection.* Replace directional panel and the directional stabilizer and turn the old units in for overhaul.

(5) *400-hour inspection.* Replace both pot assemblies in vertical flight gyro and the balance pots in the servo units. Turn the old units in for overhaul.

(6) *500-hour inspection.* Replace the rotary inverter. Turn the old unit in for overhaul.

(7) *800-hour inspection.* Replace all tubes in the amplifier unit.

c. MAINTENANCE. (1) *General precautions.* As the units of the C-1 autopilot are precision built, it is essential that they be checked and serviced only by properly trained personnel. Under no circumstances should the cases be opened or adjustments made by persons who are not qualified to service the equipment. During all servicing and inspection operations, a regular systematic procedure must be followed to insure that no parts are overlooked and that all important points of a unit are properly checked. When replacing defective units, it should be determined that the replacement unit is identical with the defective unit, and that all current changes or modifications have been complied with before it is installed. If it is found necessary to remove either of the gyro units, they must be handled with extreme care to avoid introducing mechanical errors which would seriously affect the autopilot's operation. Particular attention should be given to all soldered or terminal type electrical connections, as well as to the AN connectors on the various units.

(2) *Equipment required.* For the inspection and cleaning of the autopilot, no special equipment is required. For oiling, a long-needled hypodermic syringe is used to aid in getting the oil to the required points. For servicing, repair and adjustment, ordinary hand tools are used, with the addition of a few special tools to facilitate work on certain units. For checking the tubes and electronic circuits in the amplifier, a special C-1 autopilot amplifier test set is provided.

78. Service Troubles and Remedies

a. GENERAL. (1) *Use of wiring diagrams.* Four wiring diagrams are provided for each installation of the C-1 autopilot in a specific airplane. These are the a-c bridge circuit diagram, the d-c power supply circuit, the J-box wiring and terminal numbers, and the unit to J-box diagram. It is essential that the organization of these circuits and the lay-out of the various units on the airplane be understood before any troubleshooting is attempted. On the diagrams, as on the airplane, all autopilot wiring harnesses are labeled with a number and the letters FL. In the junction box, these wires are connected to the terminals, which are identified by a number and the letter of the terminal block, that is B8, C4, F7, etc. In the autopilot control panel, the terminals are designated by number only. In addition to the main J-box, the autopilot wiring for the directional stabilizer is run through the bomber's junction box. On some installations, these wires will change from FL to K. This is the only point in the system at which such a change will occur. No other junction

boxes, panels or Q strips are used in wiring the autopilot.

(2) *Use of J-box.* The various units and circuits of the autopilot are connected to each other in the main junction box. This is therefore the most logical point in the system at which to check them. This may be done very easily by placing the test prods of an ohmmeter or voltmeter across the proper terminals. A chart of J-box wire and terminal numbers is provided on the J-box cover. After the trouble has been found across the terminals in the J-box, it may be checked further into a specific unit by removing the AN connector of the unit and checking at this point. When using an ohmmeter, all power in the circuit or wire being tested should be turned off before any readings are taken.

b. METHOD OF TROUBLE SHOOTING C-1 AUTOPILOT. (1) *Performance of ground check.* If any trouble is reported or suspected, the operational ground check should be performed, following the procedure referred to in paragraph 6*b*. This will generally serve to indicate the nature of the trouble and may locate it in one specific unit. It will also show whether the trouble is confined to one of the control channels, or is common to all three.

(2) *Localization of trouble.* The operation of each of the three control channels may be divided into the action of four separate systems, each of which is closely dependent on the operation of the other three. These four systems are the d-c power system, the a-c bridge system, the amplifier circuits, and the servo units. (See fig. 216.) Whenever a malfunction of the autopilot occurs, the action of the controls affected should be studied closely to see if the trouble is in only one channel or if, due to interaction, it is also present in the others. Once the trouble has been traced to one channel, the four systems in that channel are checked until the defective system has been located. Finally the units in that system are systematically eliminated until the actual location of the difficulty is found. The three main control channels of the autopilot are the aileron channel, the rudder channel and the elevator channel, each of which is composed of units of these four systems.

(*a*) *Power system* (d-c):

1. Batteries.
2. Inverter.
3. Vertical flight gyro, directional stabilizer.
4. Erection cut-out and directional arm lock.

(*b*) *A bridge system* (a-c):

1. Gyro pots.
2. Servo balance pots.

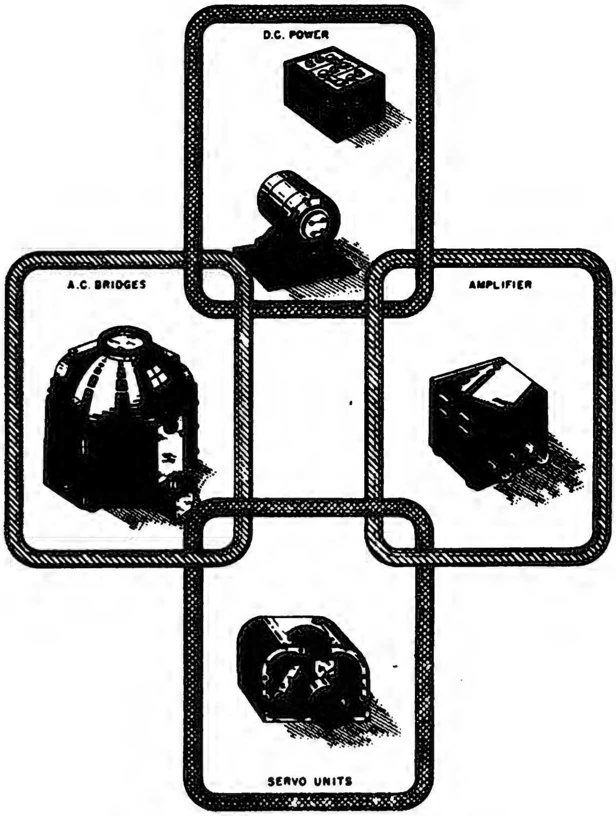


Figure 216. Relation of autopilot systems.

3. Centering pots.
4. Fixed and variable ratio resistors.
5. Turn compensation pots.
6. Turn control trimmers.
7. Turn control pots.

(*c*) *An amplifier circuit.* This includes all tubes and the tube circuits in the amplifier for a particular channel. The servo relay coils are part of the amplifier circuits, but the relay contacts are part of the d-c power system, as they close the d-c solenoid circuits in the servo units.

(*d*) *A servo system:*

1. Servo motors.
2. Operating and brake solenoids.
3. Brake switches (or ACP).
4. Limit switches.

c. PROCEDURE. Although it is impossible to give a complete list of malfunctions and the steps taken to correct them, some suggestions for identifying and locating common troubles can be described. In all cases, the first step is to perform the ground check, in order to get an over-all picture of the related actions of the units of the autopilot. If this is not done, it is possible that one particular unit may be regarded as the source of the trouble, while

in reality it is only showing the effects of trouble elsewhere in the installation. When the ground check definitely shows that the autopilot is not working correctly, an effort should next be made to see if the trouble is in one channel only, or if there is any interaction between channels. Any such interaction would indicate the presence of a short somewhere between the control or power circuits of these channels.

(1) *Power and servo systems.* Failure of all three channels to respond to control would point to a break somewhere in the main d-c power system. By actual observation, it can be determined whether or not the inverter, the gyros and the servo motors are operating. To check the circuits that control the servos from the amplifier, the rotary inverter is disconnected to eliminate the a-c part of the system, and the two relays for each servo in the amplifier unit are manually closed after the engaging switches on the autopilot control panel have been turned on. If the servos rotate in the proper directions as this is done, it is proof that the complete servo and power systems, including the telltale lights, solenoids and switches, are operating correctly. Any reversal of the servos can usually be traced to reversed solenoid or pot leads or reversed connections in the J-box.

(2) *A-C bridge and amplifier systems.* Since there are three identical signal channels in the amplifier, and since the signal from each of the three bridge circuits is fed into its amplifier channel through one lead, the trouble may be traced to either the bridge circuit or the amplifier channel by connecting the suspected bridge lead to the bridge lead of another amplifier channel. This is done in the junction box. This will place signals from a "good" bridge into the amplifier channel of the suspected bridge. As the "good" bridge's centering knob is turned, the telltale lights for both bridges should go on and off. If the lights for the suspected bridge do not operate when this is done, the amplifier section of this system must be faulty, because the signals are now coming from a good bridge. If they do operate correctly, the bridge system is defective. Once the trouble has been localized in the bridge or amplifier section, the defective section is checked further. The principal troubles in the bridge systems will be due to either an open or a ground, each of which can usually be recognized by the manner in which it affects the operation of the system. If in any of the main circuits or lines between units, they will cause the entire system to be inoperative. If in any of the adjusting circuits, they may affect the operation of only that portion of the system, or of the main system up to that point. Usually, when either a short or ground is present (unless the system is completely inoperative) one telltale light will be on, and turning the centering knobs will not put it out. The bridges and their related circuits will then have to be tested with an ohmmeter. If the trouble has been traced to the amplifier, its channels and tubes may be tested by replacing the tubes in one channel with those from another. If the trouble moves to a new channel with the tube, the tube is defective; if not, the amplifier circuit itself is defective. In addition, the six servo control relay coils should be checked to see that they are good, and the throttling controls should be placed at their correct settings. If the trouble is not cleared up by these operations, the amplifier unit should be replaced.

Trouble	*Probable cause*
(1) *Intermittent operation*	Dirty or worn pots or pot wipers, incorrect wiper spring tension, loose connection somewhere in system.
(2) *No operation*	A-c or d-c power failure, fuse blown, amplifier tube burned out, open in main circuits.
(3) *Sluggish operation*	Servo slippage, low power supply voltage.
(4) *Servo runs backwards*	Reversed leads. (Should be changed in J-box.)
(5) *One axis responds to other axis' signals*	Short circuit between channels.
(6) *Chattering controls*	Sensitivity too high, low cable tension, throttling adjustment incorrectly set.
(7) *Blinking lights but no control*	Loose lights.
(8) *Both lights on at once*	Bad relay, bad solenoid or short between lights.
(9) *All light on*	Bad tube or short in amplifier.
(10) *Improper operation from turn control*	Directional arm lock slipping, airplane not in correct attitude before engaging.
(11) *Controls do not move equally in both directions*	Servo unit limit switch needs recentering.

79. Storage and Handling of C-1 Autopilot Equipment

a. Equipment Not in Use. All C-1 autopilot equipment being held in storage or in stock for immediate issue is inspected every 15 days. At this time, the gyro rotor bearings are oiled, and the gyros are then run up for about 10 minutes to distribute the oil in a uniform film on the bearings. The other units should be checked to see that they have not been broken or damaged in any way, so that they will be available for issue and use as required.

b. Preparing Equipment for Storage and Shipment. When equipment is placed in a storage status, it will be prepared in either of two ways depending on the estimated length of time that the equipment will remain out of service.

(1) *Temporary storage.* This procedure should be used if the equipment will be in storage for a period of 1 to 4 months, or in transit on land less than 30 days. To prepare for this type of storage, the autopilot units are run up for 1 hour, and then carefully wiped free of all dust and finger marks. All exposed metal parts, except contact points, are coated with H oil, and the VFG is caged with its shipping plate. The equipment is then packed in a dry, clean case. Bags of drying agent are placed on and around the units, and the cover is tightly fastened. After 30 days in storage, the equipment should be unpacked and the gyro bearings should be relubricated. All units should then be run up for at least 1 hour. If the drying agent has become saturated, it should be replaced at this time.

(2) *Extended storage.* Equipment is treated for extended storage if it will remain out of use more than 4 months, if it is to be sent overseas, or if it will be in transit more than 30 days. The procedure is the same as that for temporary storage, except that all exposed metal parts are coated lightly with petrolatum. Every fourth month during the storage period the equipment is removed and given a check run up, and the drying agent replaced, if necessary.

(3) *Shipping and handling.* For shipment, a special heavy metal box is provided which will hold the VFG, the rotary inverter, and the three servo units. The directional stabilizer is handled separately. Every effort must be made to prevent moisture from coming in contact with the equipment, and the relative humidity inside the packing cases must be kept below 20 percent by proper use of the drying agent. For oversea shipment, the metal shipping box is placed in a heavy cardboard box, and then into a waterproof wooden shipping crate for additional protection. All persons handling the equipment should be informed as to its delicate nature, and should realize that the whole C-1 autopilot system can be made useless by unnecessarily rough handling during packing and shipment.

SECTION XV
MISCELLANEOUS INSTRUMENTS

80. General

On some airplanes, certain instruments are used which have not been discussed in the preceding sections. The only service the mechanic gives some of these is to keep them clean. Some are so rarely used that they need not be discussed in this manual. Only three of the miscellaneous instruments—accelerometers, drift meters, and aircraft clocks—will be discussed in this section.

81. Accelerometers

a. General. When an airplane, moving on an upward or a downward path, is accelerated, the vertical component of the acceleration—either upward or downward—is measured by use of an accelerometer. This amount is expressed in g-units, one g being the acceleration due to gravity.

(1) The pilot uses the accelerometer to check the vertical accelerations caused by rough air. Since such erratic accelerations interfere with the comfort of passengers, the pilot will change altitude when he finds rough weather at one level. A record of the g-units attained in flight enables the mechanic to determine the stresses to which the airplane has been subjected. This guides him in his inspection procedure. The accelerometer also serves as a test instrument for measuring the forces induced by violent maneuvers.

(2) The mechanism is inclosed in a case arranged for mounting on the instrument panel. The dial (fig. 217) is calibrated in divisions of 0.2 g-units. The range is from — 5 to 12 g-units. Downward acceleration is positive. The use of luminous paint or of a 3-volt light makes it possible to read the instrument in the dark.

Figure 217. Accelerometer.

b. Operation. (1) A type B-2 or B-3 accelerometer, shown in figure 218, contains two weights mounted on the ends of lever arms. When the airplane is accelerated vertically, inertia causes these weights to lag by an amount which is proportional to the acceleration. This lag is, in effect, a motion of the weights in relation to the rest of the instrument, and the lever arms transmit it to the two rocker shafts. Two compensating sectors are attached to the two shafts and mesh with each other, so the two weights must move equally. Another sector attached to one rocker shaft transmits the motion to the pointer staff. Restraining springs govern the movement of the weights, making calibration possible. During an acceleration to the right or left, the action of one weight, transmitted through the compensating sectors, is balanced by that of the other, so no movement of the pointers results. Neither can longitudinal acceleration of the airplane produce a movement of the weights. Stop springs limit the travel of the weights and prevent damage to the instrument. The pointer staff rotates the main pointer which is free to move over either the positive or the negative scale on the dial. Two hollow shafts, each operating one of the auxiliary pointers, fit over the pointer staff. When the pointer staff moves clockwise, the middle pointer and its hollow shaft move to the position indicating the maximum positive acceleration of the maneuver. A ratchet attached to the shaft holds the auxiliary pointer at the maximum positive acceleration reading until the adjustment screw is turned, releasing the ratchet and permitting the pointer to return to normal position. The pointer, next to the dial, turns when the pointer is turned counterclockwise and records negative acceleration.

(2) The restraining springs are so set that the pointers read one g-unit when the accelerometer is at rest in the vertical position and the force of gravity is acting on the weights.

c. Type B-1 Accelerometer. This type accelerometer has only one weight, hence it may respond

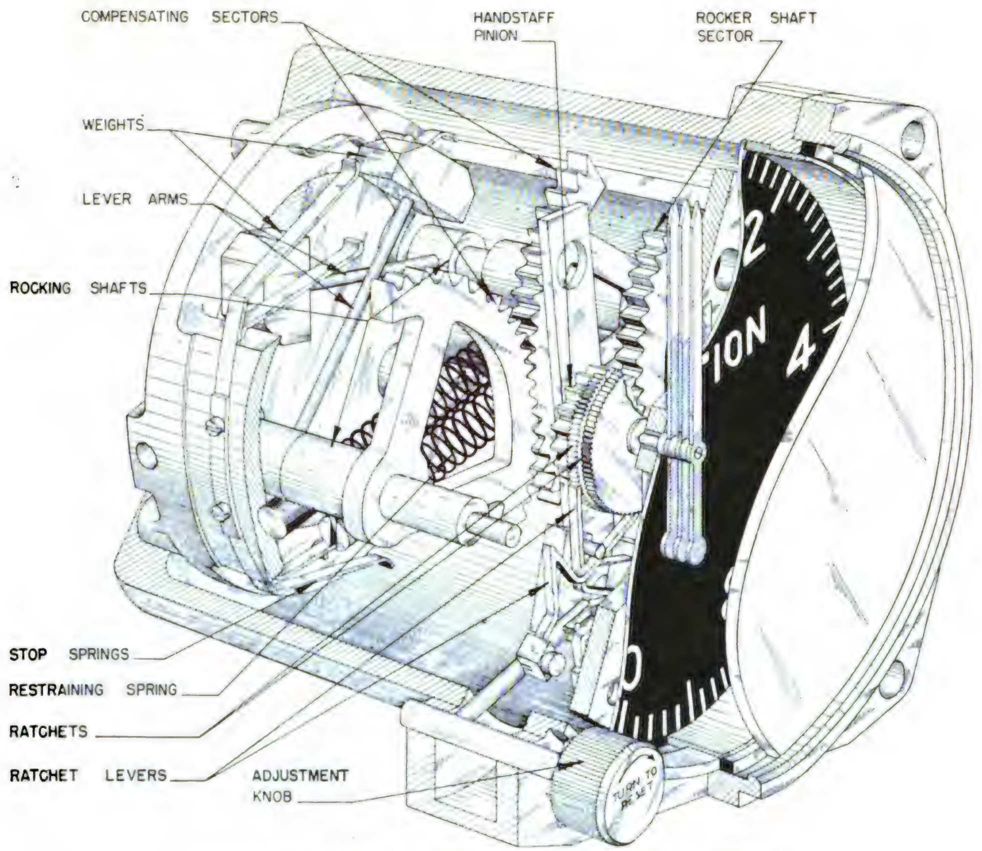


Figure 218. Type B-2 and B-3 accelerometer mechanism.

to accelerations to the right or left as well as to those which are vertical. Otherwise, its operation is quite similar to that of the B-2 or B-3 type.

82. Drift Meters

a. GENERAL. The primary purpose of a drift meter is to measure the amount of drift when flying on a cross-wind heading. In addition, it may be used to determine relative bearings, to measure ground speed by timing, to aid in swinging and compensating a compass in the air, and to aid in calibrating an airspeed indicator.

b. DESCRIPTION. Three types of drift meters are in common use:

(1) The type B-5 drift meter, in figure 219, is a periscopic instrument which is installed with the objective and extending through the side of the fuselage.

(2) The type B-2 drift meter, in figure 220, is a telescopic instrument which may be varied in length, by use of extension tubes 2, 3 or 5 feet, and which has changeable eyepieces to provide different sized images.

(3) The type B-3 drift meter, in figure 221, in-

Figure 219. Type B-5 Driftmeter.

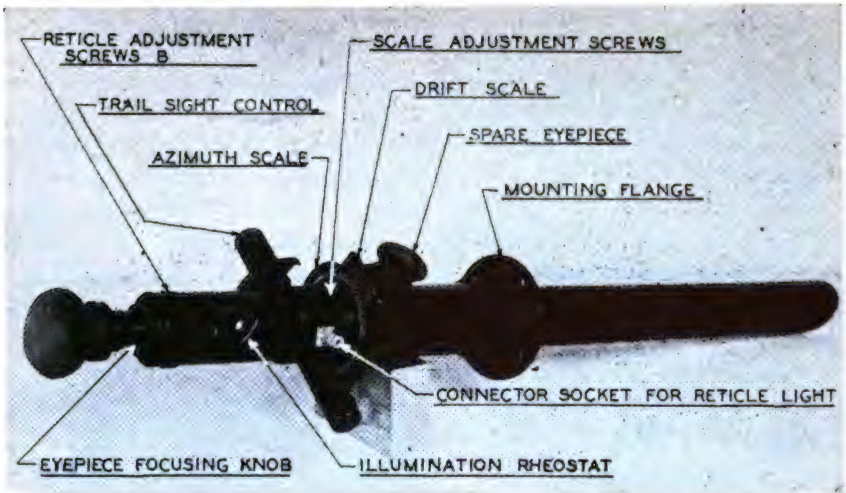


Figure 220. Type B-2 driftmeter.

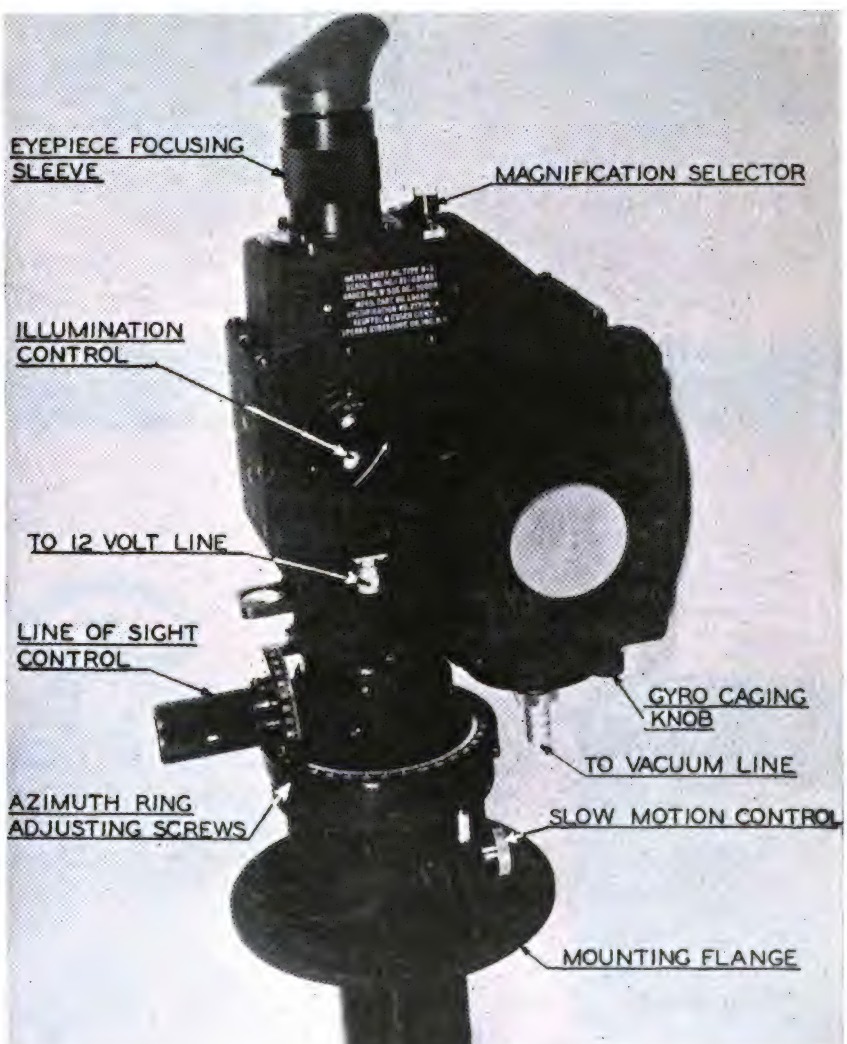


Figure 221. Type B-3 driftmeter.

corporates variable magnification equipment by means of which it can be used to measure bearings, and a gyro stabilizing unit which permits drift measurements to be only slightly influenced by pitch or roll.

83. Aircraft Clocks

a. CLOCKS. Every airplane must be equipped with accurate timepieces for use in general flight and navigation. An 8-day clock, suited for shock-free operations, is found on each standard instrument panel. All such clocks have sweep second hands, as shown in figure 222 ① and ③, while some types have special dials for "elapsed time", "time out", and "stop" (See fig. 222 ②.)

b. WATCHES. Time and stop watches of both pocket and wrist types are provided for use when working various navigation problems. Figure 223 shows one standard model of each.

① *Type A-7.*

② *Type A-8.*

① *Type A-11 wrist watch.*
Figure 223. Navigation watches.

③ *Type C-11.*
Figure 222. Aircraft clocks.

② *Type A-13 watch.*

84. Installation

a. ACCELEROMETERS. An accelerometer must be installed in accordance with applicable airplane and instrument-panel drawings and applicable Technical Order. The dial must be vertical when the airplane is in flying position, and a line from the zero on the scale to the center of the pointer staff must be parallel to the vertical axis of the airplane. If an accelerometer gives erroneous readings, it should be checked for correct installation before the instrument is removed for repair.

b. DRIFT METERS. A drift meter should be installed in the position most convenient for the one who is to use it and in the manner specified in Technical Orders.

c. CLOCKS. The Technical Orders pertaining to aircraft clocks give full instructions for installing them on the instrument panel.

85. Inspection and Maintenance

a. ACCELEROMETERS. (1) *Preflight inspection.* Check to see that the pointer registers 1 g-unit within the allowed tolerance, and that the setting mechanism operates freely and release positively.

(2) *Daily inspection.* Check for cleanliness, security of mounting, and the condition of luminous markings.

(3) *Annual inspection.* Once each year, all accelerometers—installed or in stock—shall be sent to the depot for recalibration.

(4) *Maintenance.* Little maintenance except cleaning and keeping the mounting secure can be performed by line mechanics. When the instrument does not read correctly or when it is damaged in any way, it must be sent to a depot for repair.

(5) Lubrication by line mechanics is not required.

b. DRIFT METERS. (1) *Preflight inspection.* Check to see that the eyepiece lens and the objective window are clean, and that the control turns freely.

(2) *50-hour inspection.* Inspect for security of attachment and for correct alignment.

(3) *Maintenance.* The only maintenance performed by line mechanics is to keep the units clean and securely mounted, and to remove damaged units and send them to depots for repair.

(4) No lubrication by service activities is required.

c. AIRPLANE CLOCKS AND WATCHES. The service maintenance of a clock consists of winding, setting, and checking for accuracy.

(1) Wind a clock or watch, only until it shows the first added resistance to further winding. Over winding may seriously damage the mechanism.

(2) When a clock or watch is damaged or does not keep accurate time, send it to the depot for repair and regulation.

86. General

Because aircraft instruments vary widely in construction, dependent units, and functions, the methods and procedures for the installation of the various types necessarily differ. However, some instructions which apply to all installations are discussed in this section. The detailed installation instructions for each instrument were presented in preceding sections with the general discussion of each particular instrument.

87. Mounting Panels and Connections

a. Instrument panels are generally made of 0.125-inch sheet aluminum alloy or of plastic material. On panels of excessive width or depth, it is necessary to add stiffeners to provide the required strength and rigidity. All surfaces of the panel and the faces of all instruments have a dull or black satin finish which causes the luminous markings on the dials and pointers to stand out more clearly. If crash pads are used to protect the instruments, the same color of finish is used.

b. Dimensions of instrument panels vary with the different sizes of airplanes. Normally, all of the frontal space available is required to mount the instruments. As the size of the airplane increases, the number of instruments also increases because of the additional number of engines used. On some of the smaller airplanes, the width of the fuselage in the pilot's cockpit does not permit enough frontal space on the instrument panel and it is necessary to add auxiliary panels at the sides of the fuselage for switches, control handles, etc. Height of panels may be two-, three-, or four-tier, depending upon the space available. As nearly as possible, flight instruments are located so they are on the same level as the eyes of the pilot when he is sitting in a normal position in the cockpit. All other instruments are located around this group as conveniently as possible.

c. Later specifications stipulate that the flight instruments must be mounted in a definite order on the instrument panel. These instruments are to be mounted on the left side of the panel or in front of the pilot in two rows of three each. The upper row from left to right is to include the airspeed indicator, directional gyro and gyro horizon. The lower row is to consist of the altimeter, bank-and-turn indicator, and the rate-of-climb indicator, also reading from left to right.

d. All instrument panels are vibration insulated. The standard method is to mount the panel on rubber vibration-insulating mounts. These absorbers are used in pairs; one is attached to a bracket fastened to the panel and the other to a bracket attached to a solid member of the fuselage.

(1) Periodic inspections of each of the units are required to locate any defects or breaks in the rubber cups. If a replacement is necessary, care should be taken to replace the defective mounting with one of the proper size.

(2) It is very important in installing vibration insulators that the long side be placed in compression as shown in figure 224. Inverting

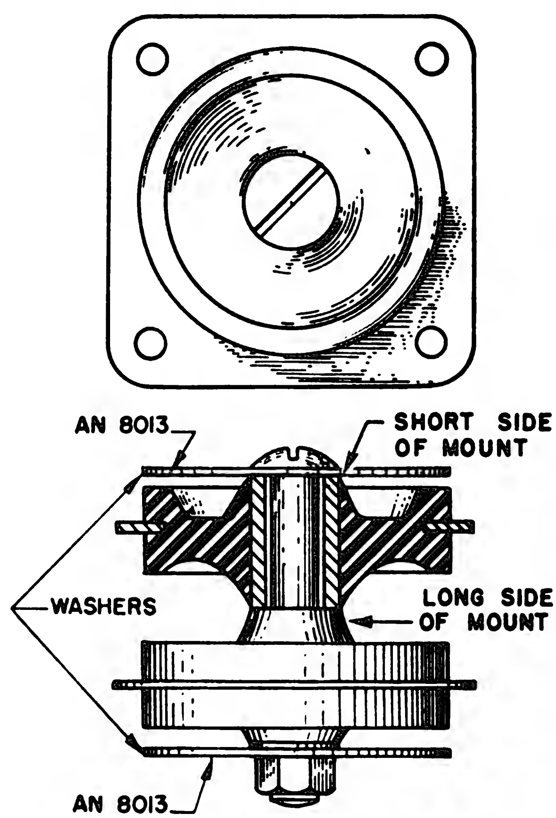


Figure 224. Shock absorbing unit for instrument panel.

the vibration insulators will seriously affect the amount of vibration of the panel. The total deflection of each part of the vibration insulator must not exceed 1/8 inch ± 1/64 inch.

c. TYPES OF INSTRUMENT CONNECTIONS. (1) Correct operation of the majority of aircraft instruments depends upon proper connection either to the engine or some of its accessories or to some other independent operating unit. Since the instruments are mounted on vibration-proof panels, each connecting line leading to or away from a panel must be provided with a length of flexible line immediately back of the instrument. Where lines made of metal tubing are used, this is accomplished in either of two ways. In most cases, a standard flexible connection is used. This consists of a 10- to 14-inch length of pressure-resistant synthetic-rubber tubing with suitable fittings at each end. Where the standard flexible connection cannot be used, it is necessary to place a coil in the tubing close to the instrument to provide the required flexibility.

(2) Electrically operated instruments are connected by either the common eyelet type of terminal soldered to the lead and secured on a binding post with a nut, or by special multiple-line plug connectors.

(3) Most instruments requiring tubing connections are provided with pipe-threaded bosses. A few have straight-threaded bosses. Care should be exercised to see that the fitting has the same kind of threads as the boss in the instrument case. The three types of fittings used are the union cone, the AC 811 and the AN standard.

(*a*) The union-cone fitting connection (fig. 225) is an older type and is seldom used. The union nipple is screwed into the instrument case. The union cone is soldered on the end of the tubing. The end of the cone is then inserted in the end of the nipple and the union nut is drawn over the cone and screwed on the nipple. This completes the connection.

(*b*) The AC 811, in figure 226, is of the three-piece solderless type. The tube end of the nipple has straight threads and its end is tapered to form a bevel. The opposite end may have straight or pipe threads. The flared tubing is held against the nipple by the sleeve which has an internal bevel. When the coupling nut is drawn over the sleeve and screwed on the nipple the flared tubing is held tightly against the beveled end of the nipple.

(*c*) The AN standard type, shown in figure 227, supersedes the above types and is used in all newer installations. It is of the same basic design as the AC 811, but the angle of the bevel and the fitting and the pitch of the threads has been changed. The sleeve is also shorter

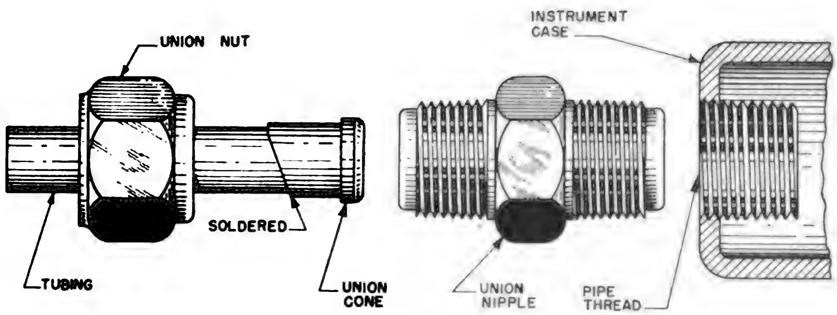


Figure 225. Union-cone type of fitting.

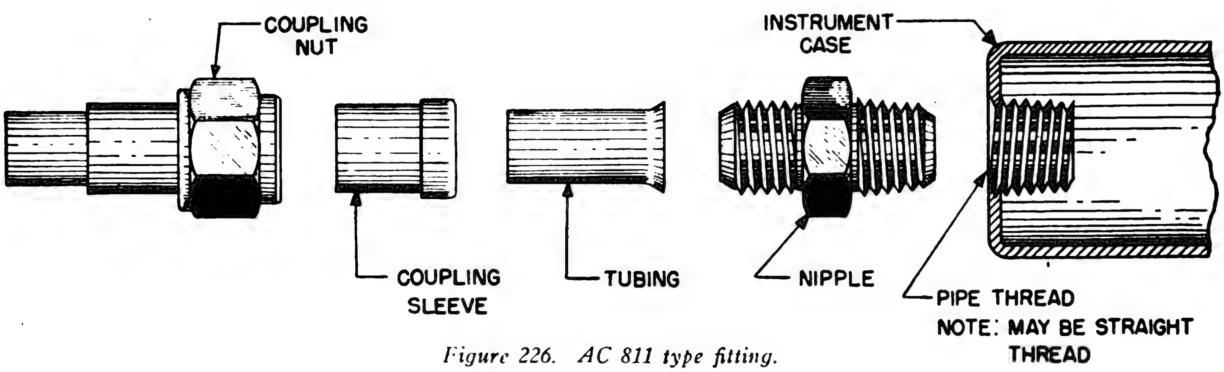


Figure 226. AC 811 type fitting.

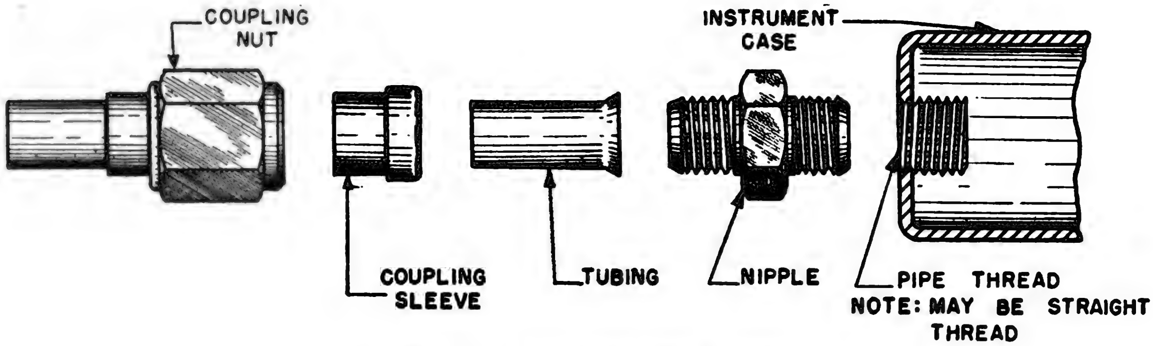


Figure 227. AN standard type of fitting.

and the coupling nut is wider. The applicable Technical Order should be consulted for information concerning the interchangeability of parts of these connections.

88. Installation Instructions

a. Standard hardware is used in all instrument installations. The tubing diameter and wall thickness end of the required types of connections or fittings are specified for each installation by Technical Orders and installation drawings. All tubing should have a minimum number of bends. In vacuum lines, particularly, the bends should have radii as large as possible. Connections may be any of those listed above. Care must be taken, if the connections are threaded, that the correct thread is used in each case.

b. All connecting lines, tubes, leads, capillaries, etc., should be securely anchored and properly bonded. Unless otherwise directed, all replacements are duplicates of the original installation.

c. Care must be taken to prevent breaking the connections of thermometer capillaries, liquidometer capillaries, and other calibrating units which are sealed during manufacture, as this damages them beyond economical repair.

d. Either standard shielded aircraft power and lighting cable, or unshielded cable in aluminum conduit is used to connect all electrical instruments to their dependent units. The sizes and types of wiring terminals, etc., required for each installation are specified in Technical Orders and installation drawings.

89. Front Mounting

On some new aircraft the instruments are mounted with the flange of the instrument on the face of the instrument panel. Sufficient flexible hose or electrical wire is left to permit removal of the instruments from the front of the panel. This is done to facilitate instrument maintenance. In this application self-locking type mounting nuts are installed on the panel. Consequently the nuts furnished on most instruments are not required. If the instruments are "front mounted" it will be necessary to remove the mounting nuts prior to installation. This should be done with the aid of a *hand* drill or a special tool as shown in figure 228. Never use an electric drill for this purpose as binding of the drill is likely to result in a broken instrument mounting lug. New instruments of types

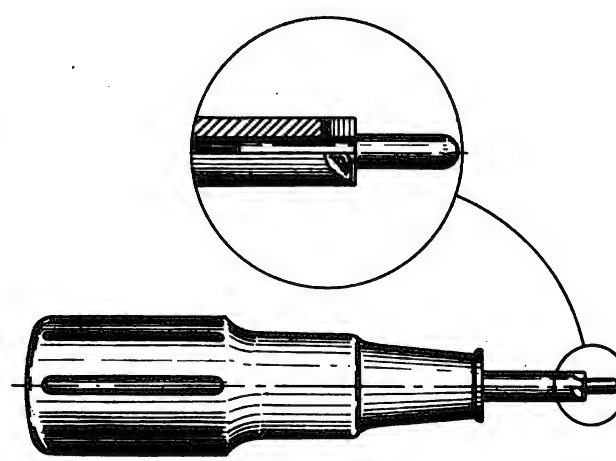


Figure 228. Tool for removing mounting nuts.

not previously used will be supplied without mounting nuts. However, until "front mounting" is the universal practice, the inconvenience of removing nuts will be required. A new type of nut which can be quickly attached or removed from the instrument or panel is being adopted to facilitate the front-mounting program.

SECTION XVII
MAINTENANCE, STORAGE, AND REPAIR

90. General

Line maintenance of aircraft instruments consists essentially of performance of the specific items of maintenance on the various instruments as outlined in sections II through XV. In any case where minor adjustments as previously prescribed have failed to correct the malfunction, the instrument will be replaced with a new or a serviceable used instrument.

91. Removal and Replacement

a. Instruments are removed and replaced for any of the following reasons:

(1) Failure to give any indication.

(2) Inaccurate indication (in excess of allowable tolerances).

(3) Damaged case.

(4) Loose pointer.

(5) Loose or cracked cover glass.

(6) Defective lamp receptacles.

(7) Broken or cracked mounting lug.

(8) Defective setting or caging mechanisms.

(9) Defective binding posts, connecting nipples, and AN connectors.

(10) Dull or discolored luminous markings.

(11) Any known or suspected malfunction of the internal mechanism.

b. The removal and replacement of aircraft instruments requires special care and careful attention. Some of the particular considerations necessary are as follows:

(1) They should be handled carefully at all times and treated with the same care that would be given an expensive watch.

(2) An instrument is always replaced with another of like kind and type (unless higher authority gives specific permission to the contrary).

(3) The location of any instrument or its dependent units must not be changed without proper authority.

(4) When an instrument is being checked or tested, care must be taken not to subject it to undue or abnormal overload. (Design factors of safety permit some overload but undue abuse will render a gauge or instrument completely valueless.)

(5) When making connections to the instruments, care should be exercised and "strong-arm" tightening methods must be guarded against.

(6) Instrument pipe thread lubrication compound should be used on the male fittings of all threaded connections.

92. Common Duties

The duties of the instrument specialist include the following:

a. Determining whether an instrument operates satisfactorily. This may be done with the instrument installed on the aircraft or after the instrument has been removed from the aircraft.

b. Minor repair, which consists solely of removal and replacement of cracked cover glasses. The cover glass may be attached to the instrument case by means of a snap ring or a cover glass hold-down ring.

(1) When removing a snap ring, the correct type tool must be used. After the snap ring has been removed, the sealing compound should be scraped away with a pointed orangewood stick. A suction cup may then be used to remove the cover glass.

(2) To remove the cover glass from an instrument which employs a cover glass hold-down ring, it is first necessary to remove the ring screws. As the screws are made of brass and are easily damaged, it is essential that the proper size screw driver be used. If a screw slot has been enlarged to such an extent that the screw driver slips, it will be necessary to drill the screw and remove it with a screw extracting tool. The seal and seal screw must be removed before any attempt is made to lift the ring from the case. After removal of the ring and gaskets, the cover glass may be removed. Penetrating oil may be used to facilitate removal of corroded screws.

(3) When replacing a cover glass, use the following procedure.

(*a*) The dial of the instrument is dusted with a camel's-hair or soft-bristle dial brush.

(*b*) The pointer is inspected for proper attachment and correct zero setting.

(*c*) The cover glass is inspected for correct thickness and cleanliness.

(*d*) After gaskets (if used) are properly installed on a snap ring installation, the cover glass is replaced, suitable sealing compound applied, and the snap ring inserted. On a hold-down ring installation, the gaskets, and lighting ring are properly placed in their respective positions. The cover glass is then replaced in the case, the ring set in position, and the screws securely tightened. The seal screw should be resealed.

c. Adjustments include the following:

(1) Setting zero.

(2) Setting temperature on thermocouple instruments.

(3) Adjusting sensitivity of Flux Gate Compass.

(4) Compensation of compasses.

(5) Other adjustments specifically provided.

93. Packaging, Storage and Shipment

a. GENERAL. Two general methods are used in packaging instruments. In the newest and most desirable method, the instrument is packaged in a metal container which is lined with shockproof material. In the older method, the instrument is packaged in a cardboard box which contains a shock-resisting material such as tissue paper, strips of corrugated paper, etc.

(1) Metal containers are clearly marked to indicate the instrument they contain. They should not be opened until the mechanic is ready to install them on the airplane. Metal containers are airtight and contain a moisture-absorbing chemical, therefore instruments packaged in them will not corrode but will be ready for immediate installation. When replacing a damaged instrument with a new instrument packaged in a metal container, the damaged instrument will be repacked *in the metal container* for shipment to higher echelons for repair.

(2) Instruments packaged in individual boxes are protected by tissue paper, strips of corrugated paper, and packing felt which are used to pack them snugly and prevent their movement within the boxes. Excelsior should never be used for this purpose. Each individual box is securely sealed with gummed paper strips and marked with the inspector's acceptance stamp, imprinted partly on the sealing strips and partly on the box, thus providing a visual means of preventing the removal of the sealing strips without detection. Sextants, octants, chronometers, sensitive gyroscopic instruments, aperiodic compasses, etc., since they are bulky and fragile, are not stored and shipped in cardboard containers. The containers furnished by the manufacturers or the cans mentioned in (1) above are used for packaging these instruments. Venturi tubes are not packed in the boxes with instruments but are packed in separate containers.

b. After an instrument is packed in an individual box, a printed form is completely filled out and pasted on the box. The data on this form include the name of the station performing the testing inspection, date of such testing and inspection, name and type of instrument, manufacturer's part number, the Army Air Forces drawing or specification number, name of the individual performing the inspection, and the storage expiration date. With this information the contents can be identified without opening the box.

c. The regular air transport supply service is utilized for the shipment of all types of aeronautical instruments whenever feasible. The following items are extremely delicate and, if air transportation is not available, are always shipped by express:

(1) Flight indicators.

(2) Turn indicators.

(3) Navigation watches.

(4) Octants.

(5) Compasses.

(6) Automatic-pilot gyro controls.

(7) Precision (type D) altimeters.

(8) Driftmeters gyro-stabilized.

94. Reinspection and Storage Time Limit

a. When in stock, instruments will be reinspected and tested by a subdepot or depot at the expiration of a certain time. This time varies for different types of instruments, and is given in Technical Order 05-1-1. However, if there is any question as to the serviceability of instruments in storage, more frequent inspections are performed as required.

b. After reinspection, each serviceable instrument is properly packed, the container sealed, and the printed form filled out and attached. The instrument is then returned to stock for issue. If the instrument is found to be unserviceable and cannot be repaired locally, it is forwarded to the nearest repair depot for reconditioning.

c. If the sealing strips of a packing box have been broken, each instrument is reinspected for serviceability before it is returned to stock or issued for service. Each instrument in supply stock is considered unserviceable when the storage limit date as shown on the form secured to the packing box has expired. Where facilities are not available locally for reinspection, instruments are returned to the depot for reinspection.

95. Installation and Instructions

As an aid to obtaining more satisfactory installation, a folder containing "Installation Instructions" is packed with many of the new instruments. Care should be exercised in unpackaging instruments to insure that this instruction sheet is not discarded with the packaging material. When such instructions are not available, reference should be made to the proper Technical Order.

SECTION XVIII

TYPE C-1 PORTABLE-INSTRUMENT FIELD-TEST SET

96. General

a. CLASSES OF TESTS. Maintenance testing of aircraft instruments may be divided into two distinct classes: field tests and bench tests. Field tests refer to those performed without removal of the instrument from the aircraft. Bench tests refer to those where the instrument is removed from the aircraft and tested elsewhere.

b. TYPES. Two types of apparatus are used for testing aircraft instruments. Type C equipment is portable and used for line maintenance and to some extent for base functions; type A is stationary or shop equipment and is used for base maintenance. Type C-1 field test set and the application thereof are discussed in this section.

c. PERSONNEL. Only properly trained and authorized personnel are permitted to use test equipment. Such equipment and the instruments to be tested are delicate, expensive, and easily damaged through improper use.

97. Purpose and Use

a. The type C-1 test set, shown in figure 229, is a lightweight, compact, portable unit, mounted on three wheels for convenience in moving it to the vicinity of an airplane in the hangar or in the field. The unit may be transported by aircraft or truck to a remote location for field operation. It should be towed only by hand.

Figure 229. Type C-1 portable instrument field-test set.

b. PARTS OF UNIT. This unit contains various master indicators and gauges, and the devices needed to actuate the instruments which are to be tested. With it, most inspections and tests can be made without removing the instruments from the panels. By connecting the various operating devices and master indicators, the accuracy of the instruments may be determined within suitable limits. It is used to perform scale or friction-error tests, and tests to insure accurate operation of instruments during flight.

98. Description

a. GENERAL. Both fixed and auxiliary equipment are used in a test set. The auxiliary units may be removed from the set and carried into the airplane. A test-set control panel is shown in figure 230. Figures 231 and 232 show the locations of fixed units.

b. CONTROL PANELS. The panel serves as a mounting for sight control knobs, three master instruments, and a master thermometer. The knobs are numbered and marked to indicate their respective uses. All reference to control knobs in operating instructions which follow will be by number. The panel is installed in an inclined position for convenient operation of knobs and reduction of parallax error when reading the instruments. The master instruments are a type C chronometric tachometer, a type D airspeed indicator, and a differential-pressure gauge. The first two have standard scales and graduations. The differential-pressure gauge has full scale range of 10 inches of mercury, or approximately 5 pounds per square inch. During vacuum or pressure tests, the airspeed pointer will move simultaneously with that of the pressure gauge as they have a common connection. The direct-reading master thermometer is graduated in degrees centigrade.

c. POWER UNIT. An a-c and a d-c motor in a single unit are attached to the floor panel. One hundred feet of extension wire for connection to an electrical outlet are carried on a reel also attached to the floor panel. A fuse is installed in each circuit to prevent damage to an over-

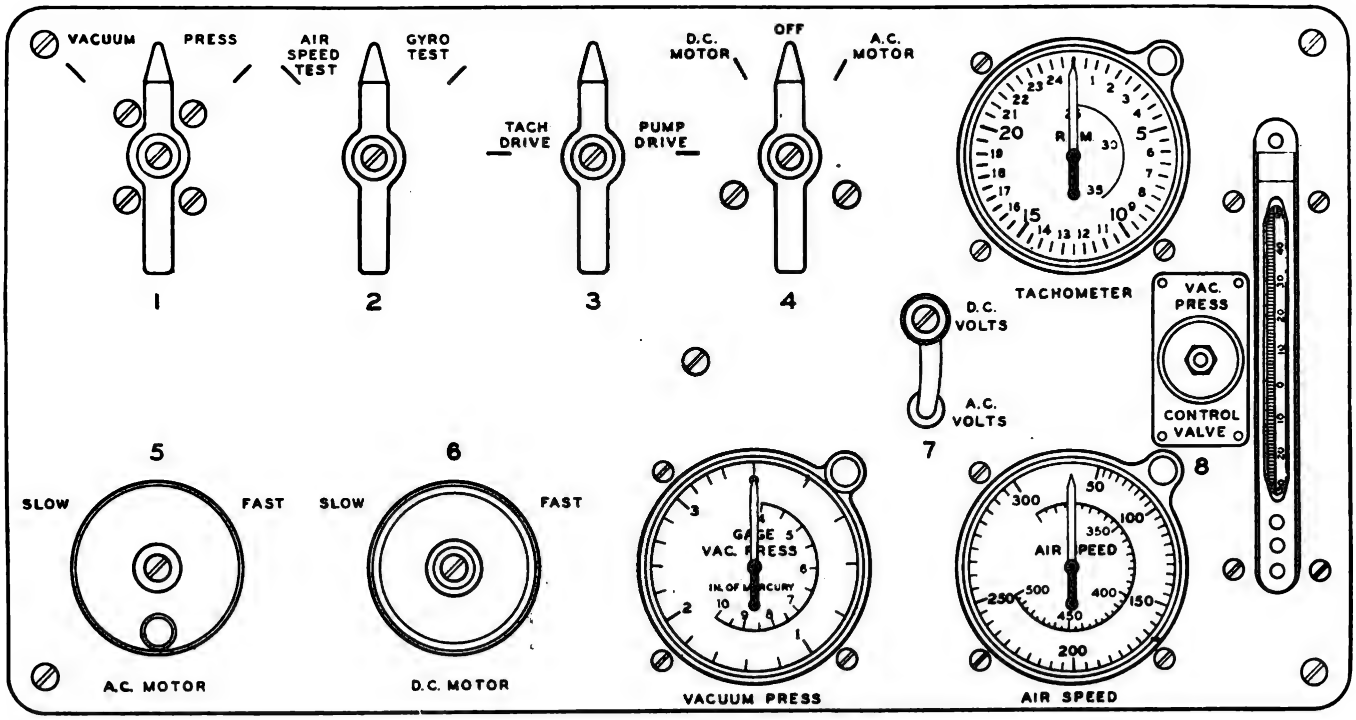


Figure 230. Control panel for type C-1 test set.

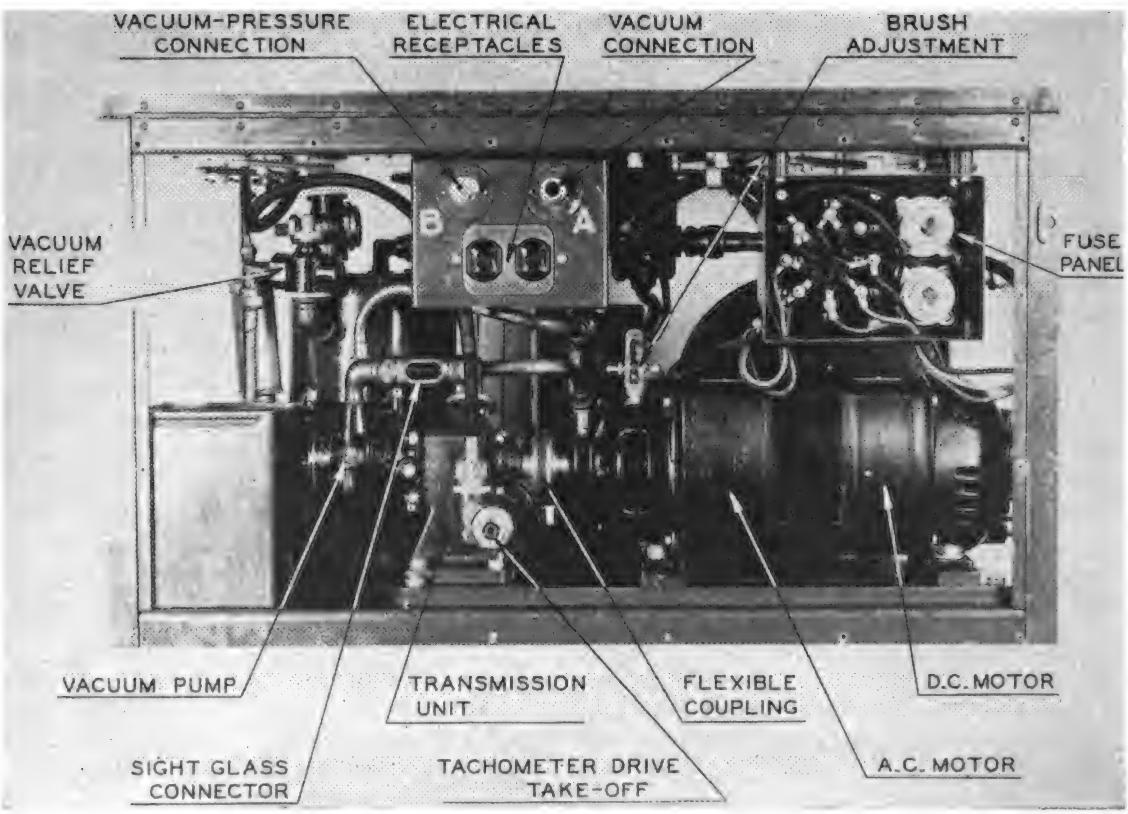


Figure 231. Type C-1 test set with rear panel removed.

Figure 232. Type C-1 test set with front panel removed.

loaded power unit. The plug type fuses are accessible through a door in the rear panel. Control knob *5* operates a ring type brush holder which holds four carbon-composition brushes on the commutator and controls the speed of the a-c motor. The control mechanism consists of a screw-thread attachment to a cable which is led through the tubing to the a-c motor. The cable is attached to a brush adjustment which has a joint designed to insure flexibility of movement. The speed of the d-c motor is controlled by knob *6* which is connected by a linkage to a rheostat located on the under side of the top panel. The power unit is connected to the bevel-gear assembly of a transmission unit by a shaft equipped with a flexible coupling. The transmission unit is provided with take-offs for driving the air-vacuum pump and the tachometer drive. A special clutch, remotely controlled by knob *3*, engages the transmission to either the air-vacuum pump or the tachometer drive. ***The power unit must be stopped before the position of control knob 3 is changed.***

d. Air-vacuum Unit. (1) This unit contains a standard airplane vacuum pump with both the inlet and outlet ports connected to a combination oil-air separator. The selector valve, operated by control knob *1*, connects the pump through the separator to a vacuum-pressure supply tank. The position of the knob determines whether vacuum or pressure will be obtained. Pressure and vacuum relief valves, connected to the supply tank, are adjustable to the maximum output of the pump. A schematic diagram of the vacuum and pressure systems is shown in figure 233. Tube outlets, ¼-inch and ⅜-inch in size, used respectively for the pressure and vacuum connections, are accessible through a door located in the rear panel of the test set. The ⅜-inch outlet *A* is used for connection to gyro instruments. The ¼-inch outlet *B* is used for testing pitot static tubes, fuel-pressure gauges manifold-pressure gauges or suction gauges. Pressure or vacuum may be obtained by correct setting of knobs *1* and *2*. A filter is located adjacent to the supply tank in the line leading to the pressure-vacuum (¼-inch) outlet. A needle valve in the same line provides for delicate adjustment of pressure or vacuum, and is controlled by knob *8*.

(2) A combination, two-compartment oil-supply tank and oil-air separator is installed

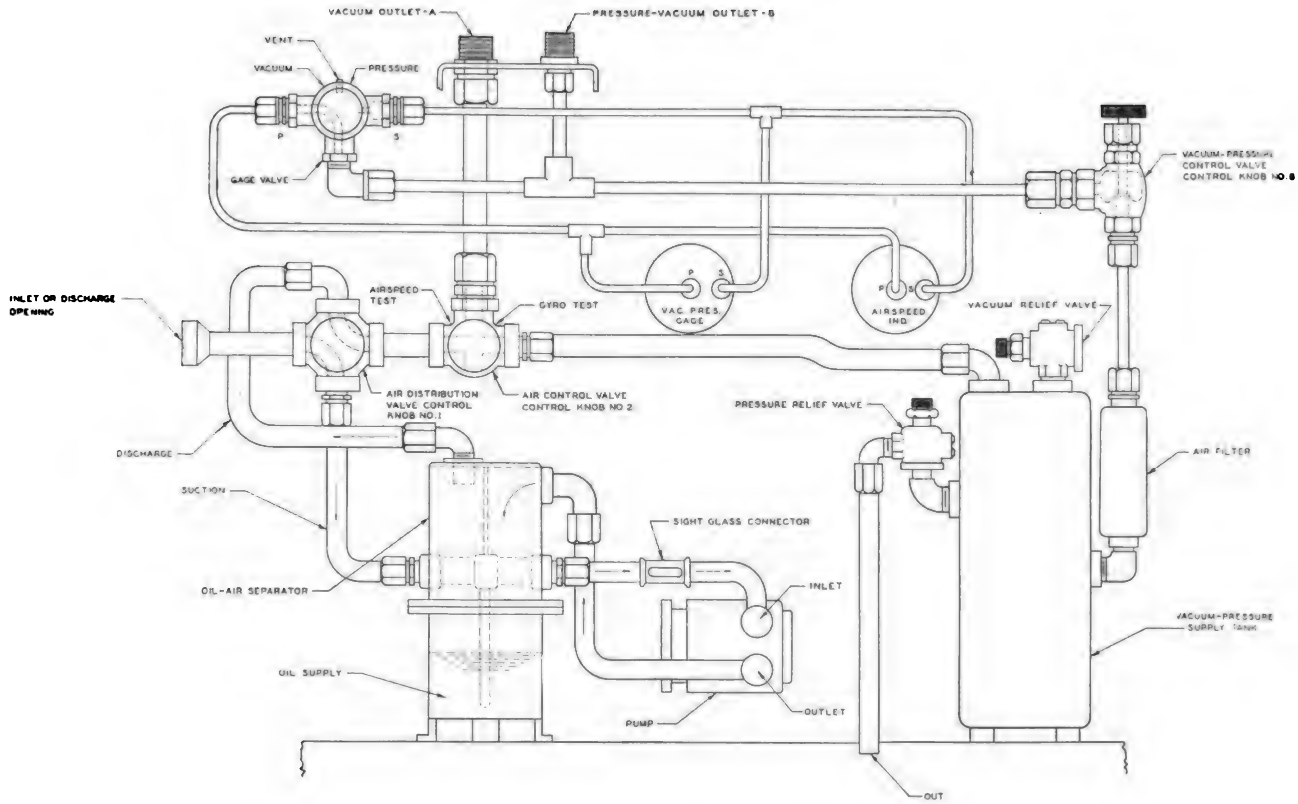


Figure 233. Diagram of vacuum and pressure systems, type C-1 test set.

between the vacuum pump and supply tank. A line connects the oil tank or lower compartment with the inlet port of the vacuum pump, and the outlet port of the pump is connected to the oil-air separator or top compartment. Oil is drawn into the pump as a means of lubrication and as a seal for efficient operation. A sight-glass connector in the line between the oil tank and the inlet port indicates the quantity of oil vapor entering the separator unit. The separator unit contains a series of baffles whereby a quantity of oil is removed and returned to the oil-supply compartment. Any remaining oil and all exhaust air passes into the supply tank or is bypassed overboard through a screen discharge opening. Under normal operation when the pump is receiving proper lubrication, a slight amount of oil vapor is exhausted to the tank or the atmosphere.

e. Electrical Outlets. Two standard 110-volt outlets for two-prong plugs are mounted on the same panel with the pressure and vacuum connections. These electrical outlets provide current for extension lights, electric soldering iron, etc.

f. Master Pressure-gauge Unit (Hydraulic). This unit (fig. 234), contains a cylinder equipped with a manually operated piston for obtaining desired pressure. An oil reservoir located on the top of the cylinder is connected through a control valve to the inside of the cylinder. A flexible rubber tube connects the control valve to the gauge under test. The master gauge, connected to the right side of the cylinder, is scaled with unit graduations of 1 pound per square inch and has a range of from 0 to 300 pounds per square inch. In addition to testing engine-oil pressure gauges, the unit may be used for testing fuel-pressure gauges, automatic-pilot oil-pressure gauges, and to a limited extent landing-gear pressure gauges. Instructions for performing these tests are given in paragraph 99*e*. This unit is also used for filling and bleeding the lines in the type A-1 pressure-transmitter system used with some fuel and oil-pressure gauges and for servicing oil-pressure gauge lines for cold-weather operation. (See par. 6*a*(4).)

g. Master Altimeter Unit. This unit (fig. 235) consists of a standard Army Air Forces type C sensitive altimeter mounted in a carrying case. A ratchet in the panel of the case manually vibrates the altimeter to remove any error due to friction. A correction card showing

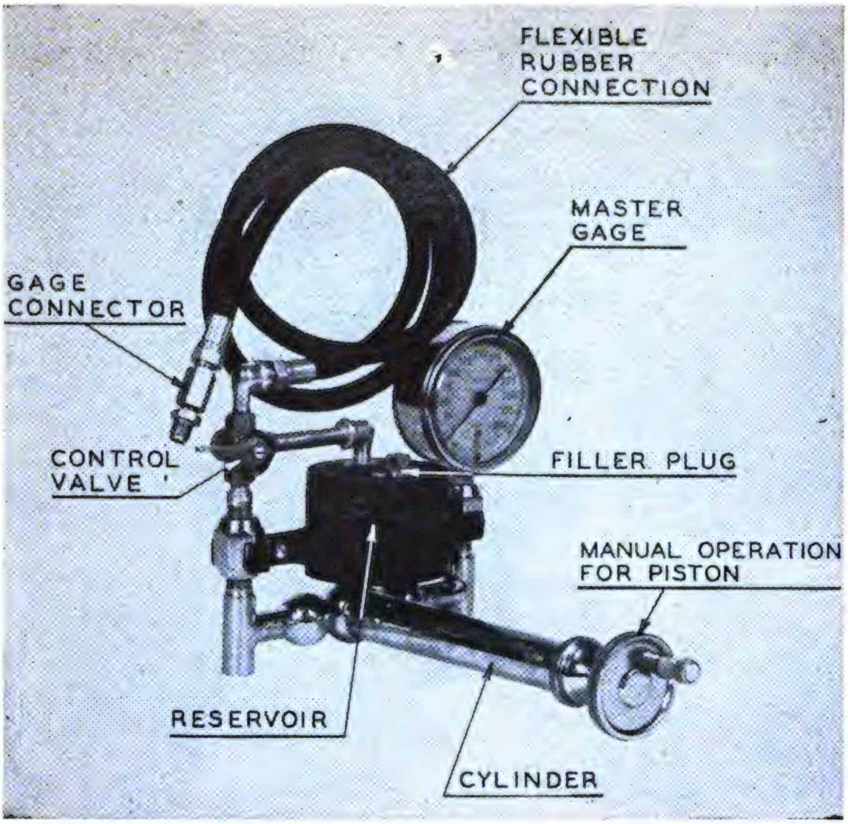


Figure 234. Master pressure-gauge unit.

Figure 235. Master altimeter unit.

the accurate calibration of the unit is placed in a holder inside the top cover. The entire assembly may be removed from the test set and carried into the aircraft.

h. THERMOMETER TESTER UNIT. The thermometer tester unit (fig. 236) is designed for testing a cylinder-temperature indicator. It contains a millivoltmeter in a hardwood carrying case. The case is designed with a compartment in the top cover for a direct-reading master mercurial thermometer, small screw driver, and a set of leads provided with alligator terminal grips for attachment of the test unit to the circuit of the thermocouple. The millivoltmeter is sealed in millivolts and degrees centigrade. It is manually controlled with the two rheostats inside the case. One is a combination master switch with adjustment for zero pointer position, and the other a switch for selected scale-range positions. A plunger type safety switch controlled by the opening or closing of the top cover, is installed in the panel. If the master switch is left in the "On" position, the current flow is automatically interrupted when the top cover is closed.

i. ELECTRIC CONTINUITY-METER TESTER. This unit (fig. 237) is a combination milliammeter, voltmeter, and ohmmeter mounted in a composition case. It is equipped with receptors marked for scale and range values. Two toggle switches select either a-c or d-c volt, ohm, ampere, or

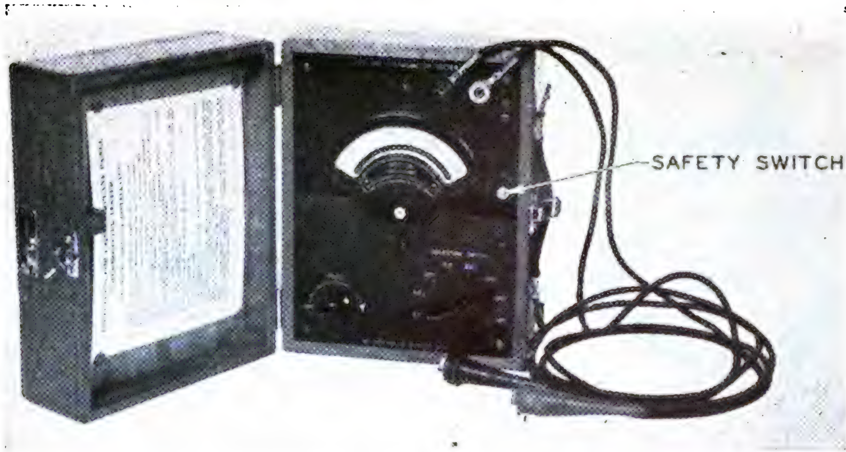


Figure 236. Thermometer-tester unit.

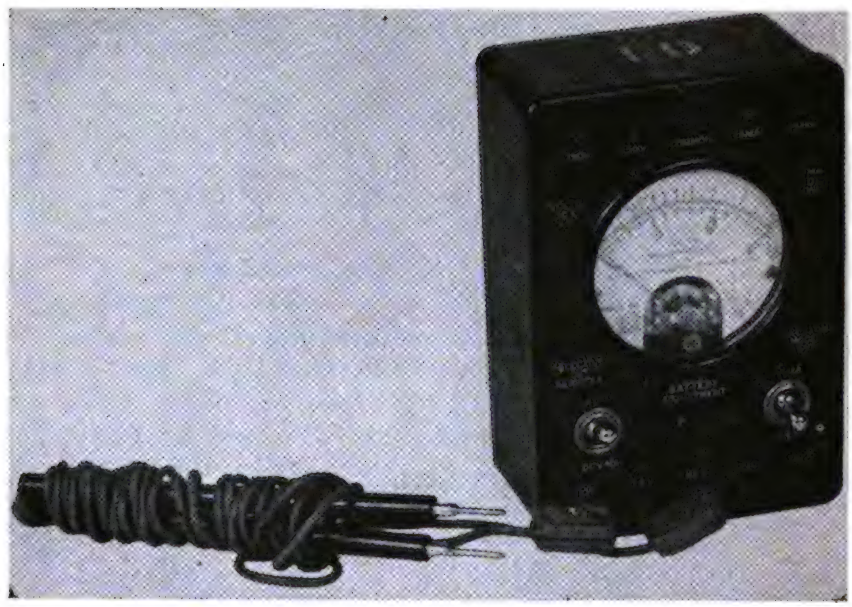


Figure 237. Electric continuity meter tester.

milliampere scales. A set of leads complete with plug and rods is furnished with the tester. The unit is used to test voltage and resistance in aircraft electric circuits.

j. ACCESSORIES AND ATTACHMENTS. Additional accessories and attachments shown in figure 238 are used with the type C-1 test set.

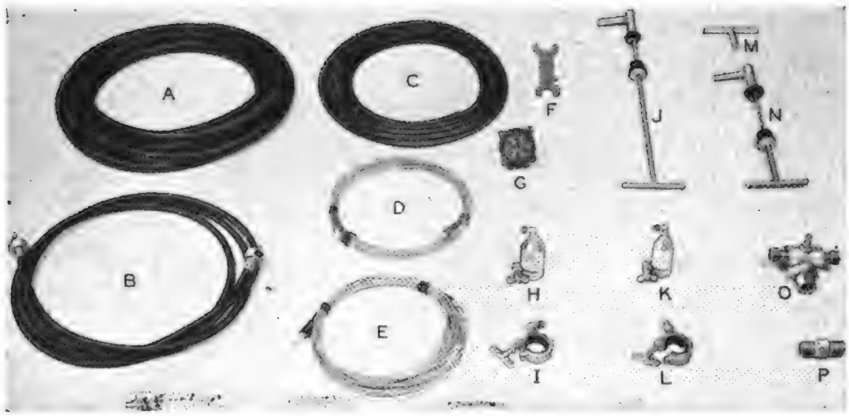
99. Operation

a. The test set is equipped to operate on 110 volts alternating or direct current. Recommended practice is to use alternating current at permanent or base stations. When operating in the field where alternating current is not available, a power-plant unit should be used to supply direct current (See Technical Order for instructions) in which case it may be necessary to increase the voltage slightly above 100 volts to compensate for voltage drop through the line and to obtain sufficient motor speed for checking the tachometer.

b. Before connecting the test set to the source of power, the following operations should be performed:

(1) Set control knob *4* to the "Off" position.

(2) Set control knob *7* to the appropriate position, that is, either d-c volts or a-c volts, depending upon the source of supply; control knob *4* can then be adjusted only to the source indicated by control knob *7*.



A and *C*. *Flexible-rubber tubing.*
B. *Tachometer flexible drive shaft.*
D and *E*. *Test leads.*
F. *Combination open-end wrench (2).*
G. *Suction gauge.*
H and *K*. *Pitot fixtures.*
I and *L*. *Static fixtures.*
J and *N*. *Venturi seals.*
M. *Hose-connecting tee.*
O. *Tachometer drive adapter, two-way.*
P. *Tachometer drive adapter, 180°.*

Figure 238. Accessories and attachments—type C-1 test set.

(3) Close control valve *8*. This is a needle type valve and should not be tightened too firmly.

(4) Set control knob *5* or *6* (depending upon the source of supply) to "Fast" position.

(5) If the vacuum-pressure system is to be used, set control knob *3* to "Pump Drive," otherwise set it to "Tach Drive." (Never attempt to change the position of control knob *3* while the motor is operating.)

c. The current is applied after the operations described are performed. As all instruments are designed to operate under vibration, the panel should be tapped lightly to overcome friction and prevent sticking of the pointer when an instrument is tested without engine operation. Connections between the test set and the aircraft instruments should be made as close to the engine as possible. The tests should be conducted as outlined in paragraph 99.

100. Application

a. TESTING TACHOMETERS. The scale-error test may be performed on either the chronometric or electric tachometer. This is merely a check of simultaneous readings on the aircraft instrument and a master indicator.

(1) *Chronometric tachometer.* Disconnect the aircraft tachometer shaft at the engine and connect to the auxiliary flexible drive shaft which

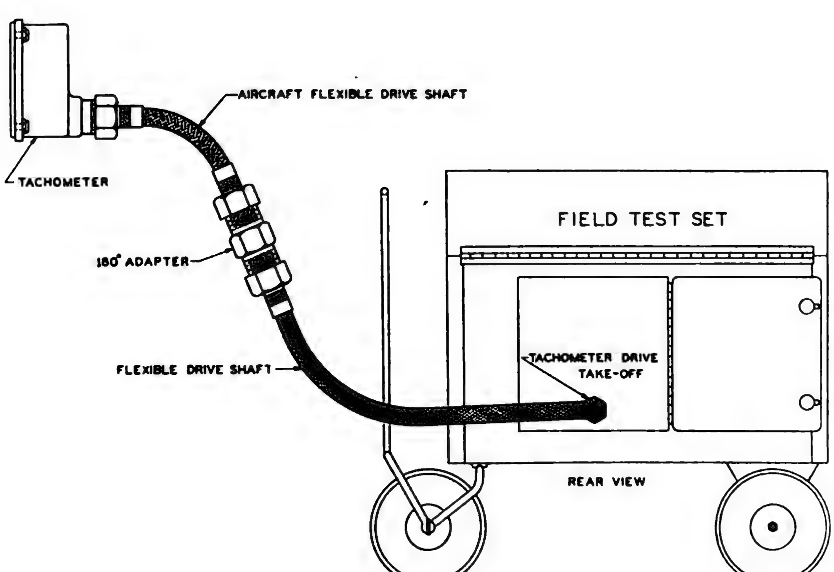
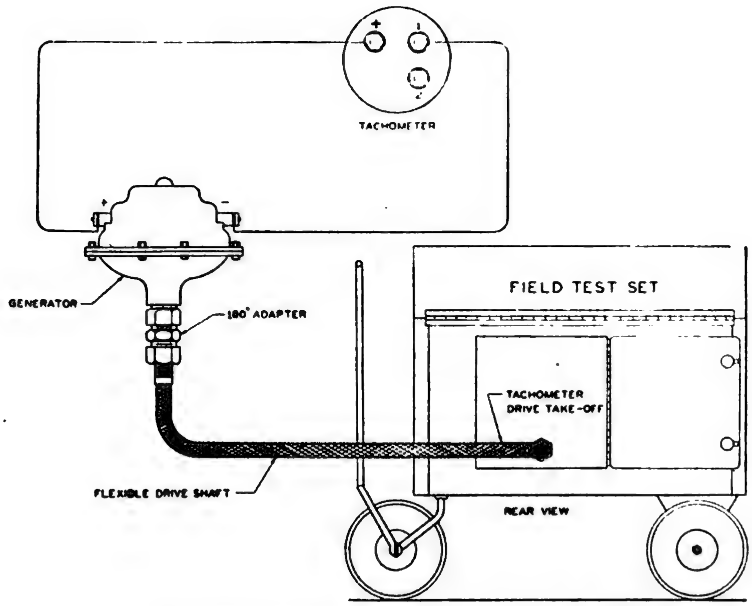


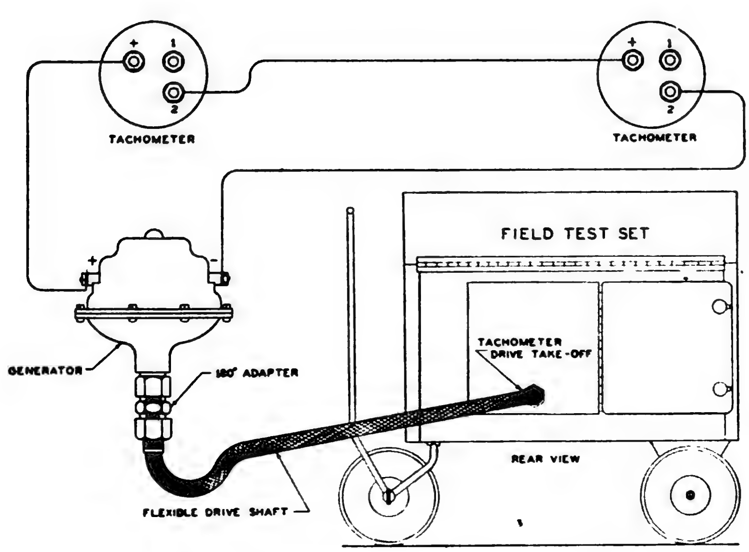
Figure 239. Connection for chronometric tachometer (shaft-driven type) test.

should be attached to the tachometer-drive take-off in the rear of the test set as shown in figure 239. Avoid any bends of less than 6-inch radius in the flexible shafts. Set control knob *3* to "Tach drive" and knob *5* or *6* (depending on whether alternating current or direct current is used) to "Fast" position; then set control knob *7* for the type of current to be used and control knob *4* to desired position. Adjust the motor speed so that the master tachometer reads even hundreds, starting at either low or high speed (the low speed of the motor should not be below 500 rpm.) Progress up or down the scale and compare readings of the airplane instrument with those on the master indicator. If the readings differ by more than the amount specified in the Technical Order, the aircraft tachometer should be replaced.

(2) *Electric tachometer.* Disconnect the tachometer generator from the drive on the engine and connect the flexible drive shaft from the test set to the drive end of the tachometer generator, as shown in figure 240. Avoid bends of less than 6-inch radius in the flexible



① *Single tachometer-indicator installation.*



② *Dual tachometer-indicator installation.*

Figure 240. Connections for electric tachometer (generator- voltmeter type) test.

shaft. Operate the test set and note whether the polarity of the generator is correct. If not, reverse the leads at the tachometer generator. The test procedure is the same as outlined for the chronometric (shaft-driven) tachometer. Make comparative readings of the master tachometer and the aircraft tachometer at each 100 rpm. graduation. If the readings differ by more than the amount specified in the Technical Order, the airplane tachometer generator and indicator should be replaced. Slight adjustments may be made by means of the "zero adjuster" on the tachometer indicator (voltmeter type) in the aircraft. Do not retard or advance the pointer more than one-half graduation by means of the adjuster.

(3) Where electric tachometers of the same type are checked frequently, the operation may be facilitated by the following modification. Draw a standard tachometer generator from stock. Fabricate a simple adapter to mount the generator directly on the C-1 field test set. Perform tests by connecting this generator to the ship's indicator (using a long length of copper wire) and following the procedure listed in paragraph 99*a*(2) above.

b. Tests Requiring Air Pressure. (1) The master differential-pressure gauge on the test set is used to indicate either suction or pressure. These tests are limited because of the pressure supply. The pressure (approximately 5 pounds per square inch maximum) supplied by the test unit is sufficient to test aircraft instruments through cruising and critical ranges. Tests are performed on fuel and manifold-pressure gauges, air-speed indicators, and airspeed tubes (leak test, pitot line).

(2) Connect the smaller tubing to the ¼-inch, *B*, outlet in the rear of the test set. The line connection of the instrument to be tested if broken at the engine (fig. 241) or in case of airspeed tube test, the pitot fixture is used as shown in figure 242.

(3) Set control knob *1* on "Press" (pressure), knob *2* on "Airspeed Test," knob *3* on "Pump Drive," and control knob *8* on "Closed". Next apply current to the motor (control knobs *4* and *7*) and adjust the pump speed with control knob

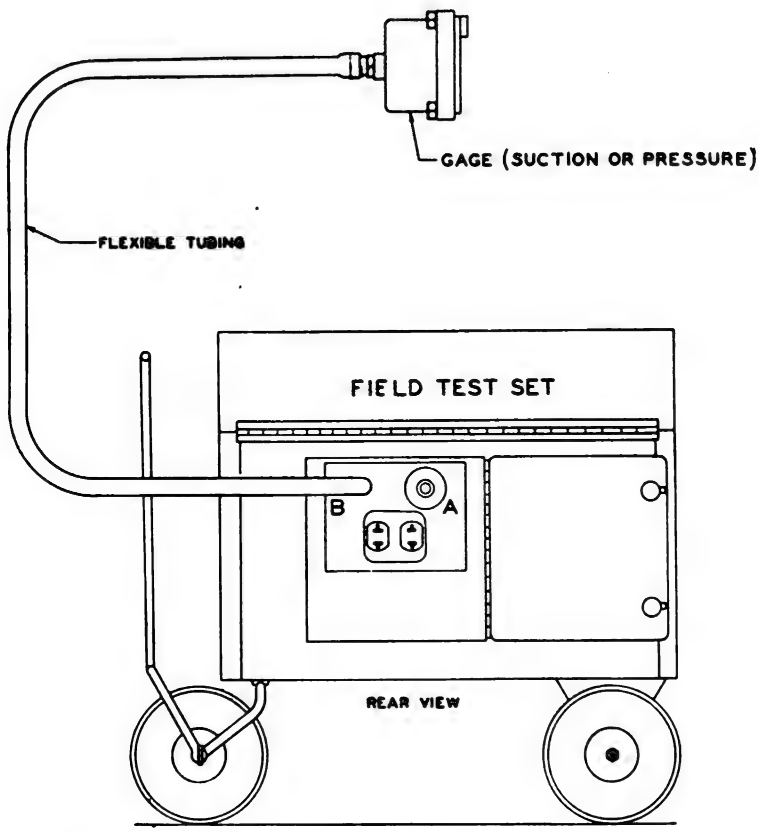


Figure 241. Connection for suction or pressure-gauge test.

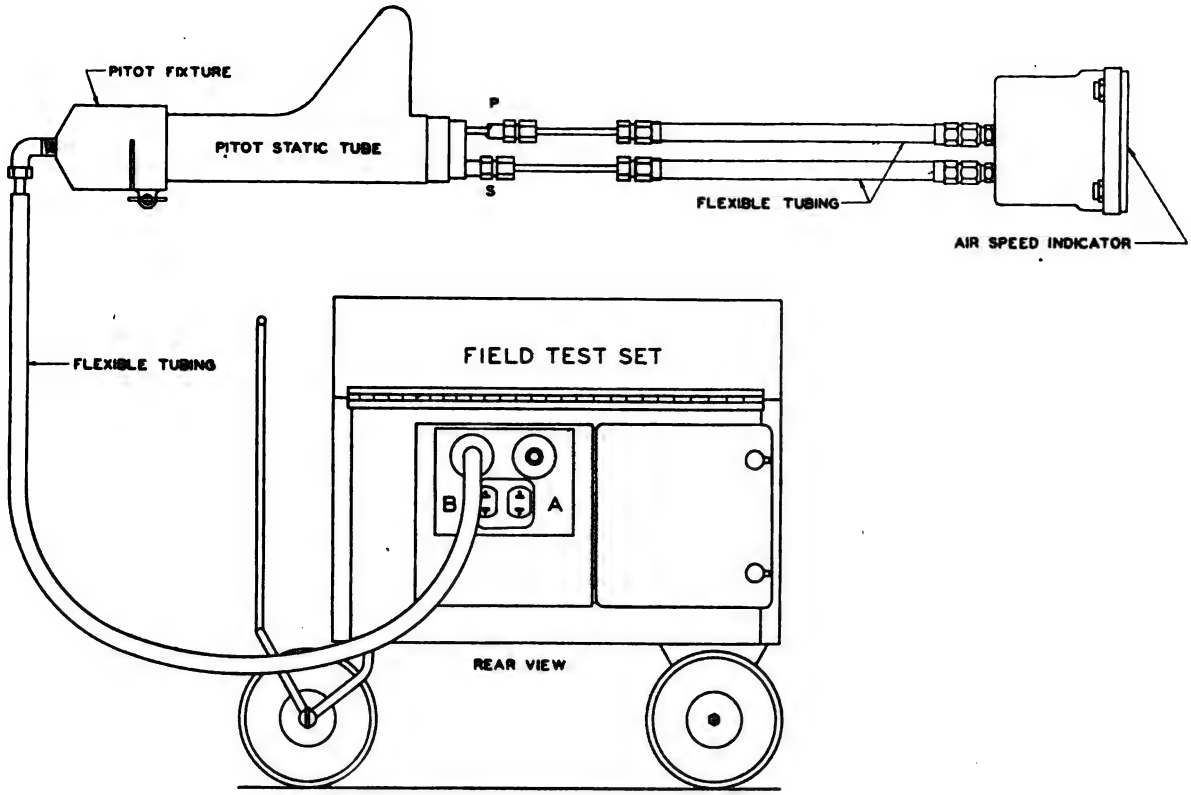


Figure 242. Connection for airspeed tube test (pitot fixture).

5 or *6*. Slowly move control knob *8* to the open position and compare the readings of the aircraft instrument with those of the master gauge.

c. Tests Requiring Suction (Except Gyroscopic Instruments). (1) These tests are also limited because of the pump supply. The tests include case leak and system tests, and are performed on manifold-pressure, fuel-pressure, and suction gauges, airspeed tubes (leak test—static line), altimeters, rate of climb indicators and airspeed indicator.

(2) Connect the smaller tubing to the ¼-inch, *B*, outlet in the rear of the test set. The line connection of the instrument to be tested is broken at the engine (fig. 241) or, in case of airspeed tube test, the static fixture is used as shown in figure 243.

(3) Set control knob *1* on "Vacuum", knob *2* on "Airspeed Test", knob *3* on "Pump Drive", and control knob *8* on CLOSED. Next apply current to the motor and adjust the speed with control knob 5 or 6. Slowly move control knob *8* to OPEN and compare the readings of the aircraft instrument with that of the master gauge.

d. Testing Gyroscopic Instruments. (1) Tests are performed on the bank-and-turn indicator, turn indicator (directional gyro), flight indicator, and gyroscopic type driftmeter. They include dynamic, cardinal, starting, and alignment tests.

(2) Connect the larger tubing to the ⅜-inch, *A*, outlet in the rear of the test set. Break the vacuum line on the aircraft installation between the relief valve and the pump, if possible, and connect the larger tubing from the test set to this line. (See fig. 244.) If, however, the aircraft is equipped with a venturi tube, connect the tubing to the aircraft with venturi seals as shown in figure 245.

(3) Set control knob *1* on "Vacuum", knob *2* on "Gyro Test" and, knob *3* on "Pump Drive." Operate the motor on the set at a speed sufficient to obtain specified suction for the instruments as indicated by the suction gauge in the aircraft. The procedures for the individual tests are outlined in Technical Order for the instruments.

e. Testing Pressure Gauges (Master Pressure-Gauge Unit). Scale-error tests may be per-

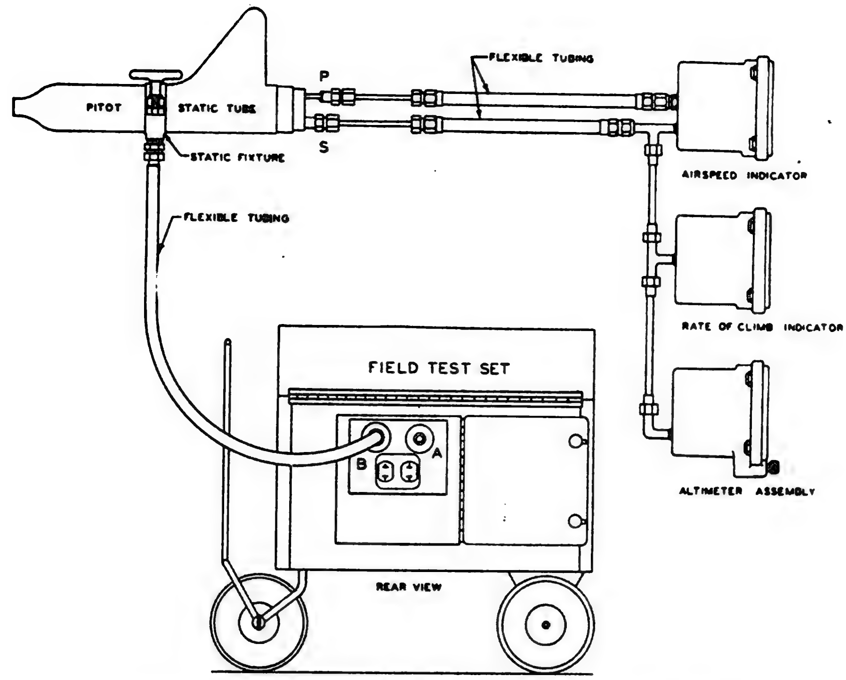


Figure 243. Connection for airspeed tube test (static fixture).

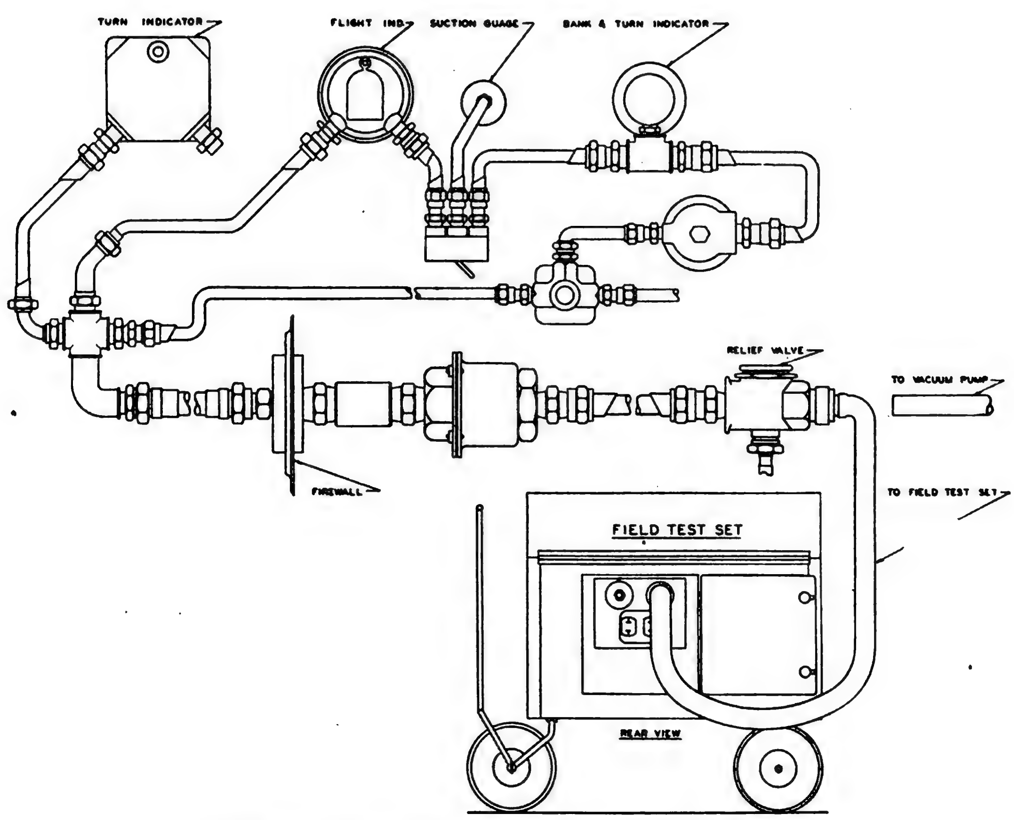


Figure 244. Connection for testing gyroscopic instruments.

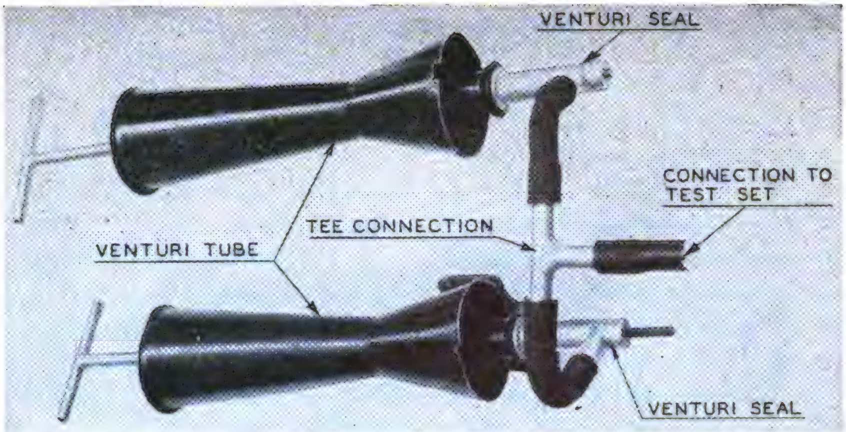


Figure 245. Connection for venturi seals.

formed on the fuel-pressure gauge, de-icer pressure gauge, and oil-pressure gauge (engine and automatic pilot). The landing-gear pressure gauge may be checked for operation up to 300 pounds per square inch.

(1) Break the pressure-gauge line as close to the engine as possible and make connections between the tester-line extension and the aircraft gauge in the manner shown in figure 246.

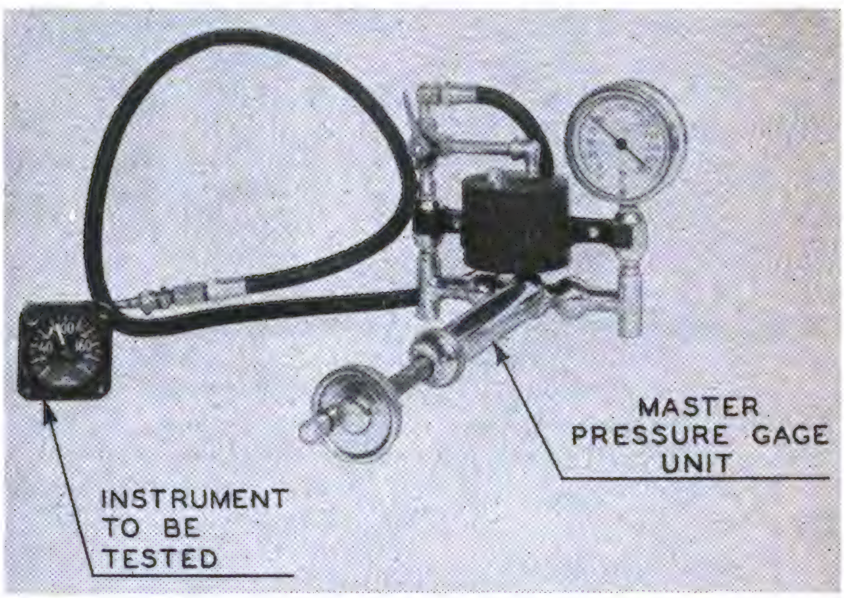


Figure 246. Gauge connection to master pressure-gauge unit.

(2) With the piston all the way in, set the control valve on the tester to "Reservoir" and screw the piston all the way out in order to fill the cylinder with oil. Then set the control valve to "Line" and slowly turn the pressure screw, checking readings of the instrument against the master gauge at a sufficient number of successive graduations. On an excessively long line it may be necessary to fill the cylinder from the reservoir several times before a sufficient supply of oil is present in the line to build up a working pressure. After the gauge has been checked throughout its range, turn pressure screw all the way out (the control valve remaining in "Line" position), then set valve to "Reservoir" and turn pressure screw all the way in. If oil has been added, permit all of the excess to run out through the filler plug in the reservoir.

f. TESTING ALTIMETERS (FOR ZERO-SETTING ERROR). The master altimeter (fig. 235), from the test set, is placed close to the one to be checked and at the same elevation. Set the reference

markers on both altimeters to zero and compare the readings of the pointers. The two readings should correspond within the tolerance specified by Technical Orders. If the difference is greater, the aircraft altimeter should be corrected as follows:

(1) Set pointers on the aircraft altimeter to correspond with those of the master altimeter, making corrections from scale correction card.

(2) Loosen (do not remove) the small screw at the left of the setting knob sufficiently that the screwhead clears the case, and then pull it all the way to the left.

(3) Pull out the setting knob and turn it until the reference markers read zero. Push the knob back, reset, and tighten the screw.

(4) If a scale-error test or any of the special tests are required, remove the altimeter from the aircraft and place it in a vacuum chamber. The master altimeter from the test set may be used as a standard if placed in the same vacuum chamber. Corrections for the master altimeter should be made from the correction card in the cover.

g. TESTING CYLINDER-TEMPERATURE INDICATOR (SCALE-ERROR TEST). (1) Disconnect the positive thermocouple lead from the aircraft cylinder-temperature indicator. Use the zero adjusting screw to adjust the pointer to 20° C. Tap the indicator lightly to prevent the pointer from sticking. Connect the positive (+) lead of the thermometer tester to the positive (+) terminal of the cylinder-temperature indicator in the aircraft, as shown in figure 247 and connect the

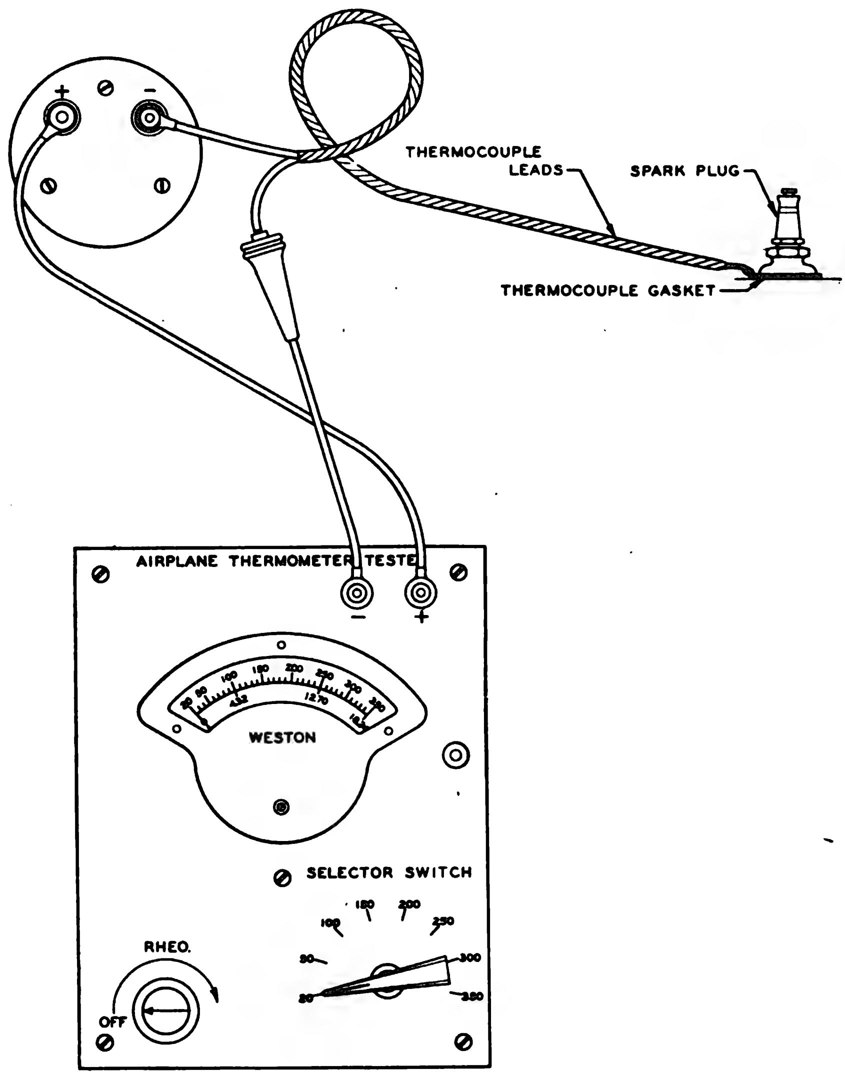


Figure 247. Connection for testing cylinder-temperature indicator.

negative (—) lead of the thermometer tester to the disconnected positive (+) thermocouple lead. The tester should be kept as nearly level as possible.

(2) With the battery switch in the "Off" position, check the setting of the thermometer tester at 20° C. mark. Then turn the battery switch of the thermometer tester to the "On" position and set the selector switch at 350° C. Adjust the rheostat until tester indicates 350° C., tap the indicator lightly to remove all friction error, and compare the readings of the tester and the aircraft cylinder-temperature indicator. Repeat for increments of 50° C. The thermometer tester and the cylinder-temperature indicator should agree within the tolerance specified in the Technical Order.

(3) After the tester is disconnected, set the aircraft indicator pointer to correspond with the reading on the portable glass thermocouple furnished with the set, then correct the positive thermocouple lead to the indicator.

h. Lead-Resistance Test. As the reading of the cylinder-temperature indicator is affected by a change in resistance of the leads they should be checked at any time accurate operation of this instrument on an aircraft installation is questioned. The thermometer tester is used for this purpose.

(1) With the tester battery switch in the "Off" position check the pointer at 20° C. mark. The lead clips should not touch each other.

(2) Turn the battery switch to the "On" position, set the selector switch at 350° C., and adjust the rheostat until the meter reads 350° C. Do not move the rheostat during the remainder of the test. Attach the flexible lead clips, one to each of the disconnected thermocouple leads, as in figure 248, and note the reading on the thermometer tester. The indication should be within the limits specified in Technical Orders.

i. Testing Voltage Drop (Pitot-Static-Tube Heating Element). The electrical circuit of the pitot-static tube is tested to determine whether the heating element is functioning properly and whether a sufficient voltage is available at the head. The following procedure may be used to check the source of supply.

(1) Remove the inspection plate from the airfoil or fuselage of the aircraft at the rear of the pitot-static boom to obtain access to the tube union and electrical "snap on" connector.

(2) Set the volt-ohm milliammeter test unit (fig. 235) with the right-hand toggle switch to "V-MA" (up) position and the left-hand toggle switch to the "DCV-MA" (down) position. Insert the plug of one lead into the receptor marked "Common" and the plug of the other into the one marked "15V". With the current supplied to the pitot-static tube, check the heating element for operation, and check the electrical circuit of the pitot-static tube with the prods of the test-instrument leads, shown in figure 249. The voltmeter readings should be within the tolerance as specified in the Technical Order.

101. Inspection and Maintenance

a. To insure efficient operation of the test set, inspect the various parts regularly and perform necessary maintenance as follows:

b. Weekly. Check the tires and maintain a pressure of 20 pounds in each.

c. Monthly. (1) *Motor.* Clean and polish the commutator with a clean cloth. No oil or emery cloth should ever be used. Roughness of the commutator may be removed by use of a fine grade sandpaper. When brushes are replaced, fit a sheet of fine sandpaper around the commutator, with sand side out and rotate it by hand in the correct direction until the brushes fit. Do not use emery cloth. Lubricate the bearings with the specified cup grease.

(2) *Transmission unit.* Lubricate the transmission with the specified oil.

(3) *Pressure-vacuum system.* Inspect the lines and valves of the pressure-vacuum system for leaks. If valves are difficult to operate, they should be lubricated with the specified grease. To prevent oil reaching the instruments on the aircraft during tests, remove the brass or bronze wool from the air filter and wash out all dirt and oil with gasoline. To check for oil vapor, operate the test set for an airspeed check and hold a sheet of clean white paper over the ¼-inch, *B*, outlet. Any oil vapor present will immediately appear on the paper.

(4) *General.* Check all bolts, screws, electrical connections, etc., for security. Lubricate moving parts, such as reel assembly, and motor and valve controls, with the specified engine oil.

d. Yearly. Repack the wheel bearings with the specified aircraft grease.

e. Overhaul. When maintenance which is beyond the scope of station personnel becomes

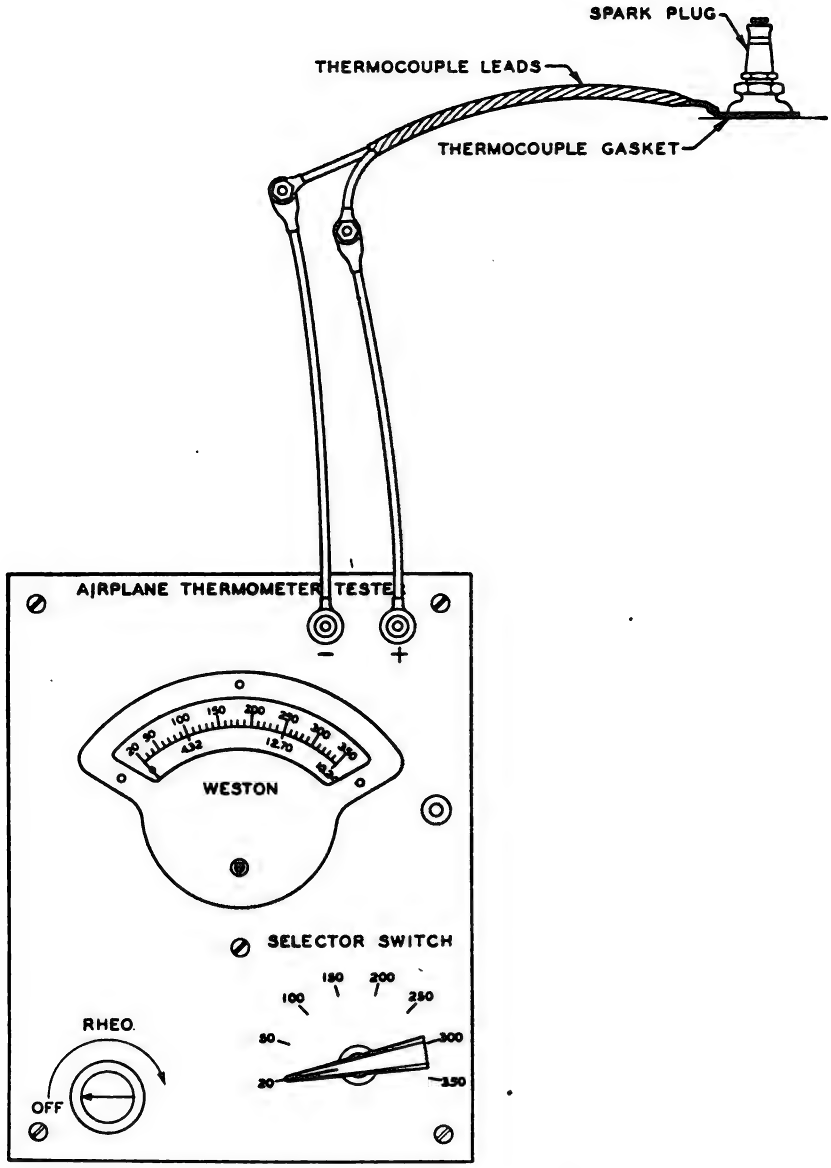


Figure 248. Connection for thermocouple lead-resistance test.

necessary, forward the test set to a repair depot for general reconditioning. Minor maintenance, such as the replacement of the air-vacuum pump or master instruments, may be performed by the activity concerned.

f. Master Instruments. Master instruments must be handled carefully or their accuracy will be impaired. For ready reference, calibration cards for each instrument should be kept in the holder in the top of the set. Stations or depots should check master instruments frequently for accuracy. When necessary, additional master instruments with calibration data should be requisitioned from depots.

g. Tachometer Drive Shaft. Avoid undue friction in the tachometer drive shaft as a result of sharp bends or undue strain on the casing.

h. Air-vacuum Pump Lubrication. Maintain the oil in the combination oil-air separator at the proper level. The sight glass should be observed to note whether or not pump is being lubricated. Specified oils should be used for ranges of temperature from —45° to 0° C. and from 0° C to 45° C.

i. Records. A complete record of inspection and maintenance should be kept on a suitable form.

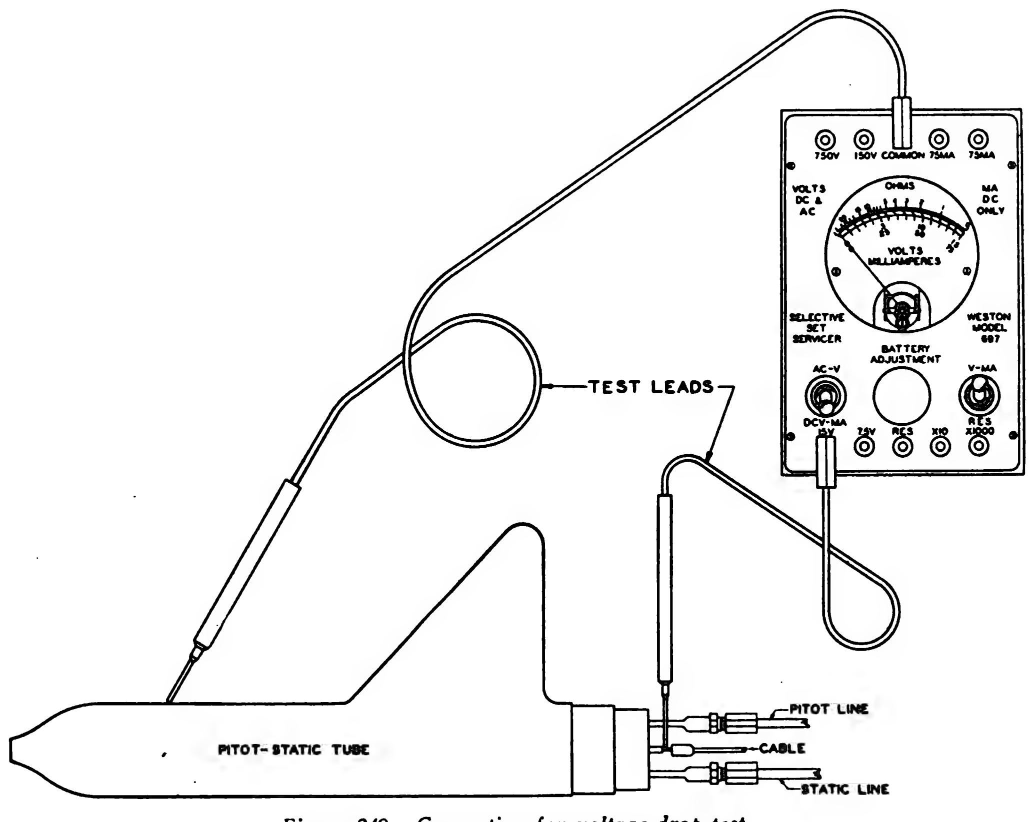


Figure 249. Connection for voltage-drop test.

SECTION XIX
INSTRUMENT TEST EQUIPMENT

102. General

The tests which may be performed with type C-1 test are limited. Various types of test equipment are used when other tests are required on aircraft instruments and related units. This equipment and its use are described on the following pages.

103. Manometer

a. PURPOSE AND USE. (1) A manometer measures pressures of gases and vapors. It is a standard for calibrating and testing differential- and obsolute-pressure instruments.

(2) The manifold-pressure gauge and the altimeter are absolute pressure instruments which are tested with a manometer. The rate-of-climb indicator, airspeed indicator, and the suction gauge are differential-pressure instruments which are tested with the same unit. When performing tests with this equipment, a source of suction or pressure must be provided. A vacuum chamber is essential in some operations. A detailed description of the vacuum chamber is given in paragraph 103*b*.

b. DESCRIPTION. (1) Manometers are U-tube or straight-tube types. To provide a large range of pressure with the manometer, various liquids are used including water (H_2O), kerosene, seal oil, and mercury (Hg). The range of a manometer depends upon the over-all length of the tube and the specific gravity of the liquid. As the specific gravity of the liquid increases, the sensitivity of the instrument decreases. Therefore if small pressures are to be measured, use water or kerosene because of their low densities.

(2) The standard test manometer used in the Army Air Forces is a straight-tube unit, shown in figure 250. It is equipped with a well which serves as a reservoir for the liquid. The liquid may be mercury, water, or kerosene. The well is constructed integrally with the tube, or separately and connected to the tube. When water is used, an aniline dye (usually red) is added to facilitate quick and accurate reading of the column. The test manometer contains a multiple scale arrangement with a scale selector and zero-adjustment knob. The various scales are shown in figure 251.

(3) Care must be exercised when reading a manometer, as curvature of the liquid level (known as "meniscus") varies for water and mercury. Figure 252 shows the meniscuses for water and mercury and the levels at which the readings are taken.

(4) When working with manometers it is advisable to remember the following common relationships: 29.92 inch Hg = 760 mm Hg = 34 feet H_2O = 14.7 pounds per square inch.

c. APPLICATION. (1) Inasmuch as the scale-error test of an airspeed indicator necessitates the use of a multiple-scale manometer, this will be used as an example. Many instruments may be tested and calibrated with the manometer. The Technical Order for the particular instrument should be consulted for details.

(2) Figure 250 shows the connections for the manometer and the pressure supply; the panel of the vacuum chamber serves as a mounting base for the airspeed indicator (connected to source of supply). The test is merely one of comparison, that is, the readings of the instrument under test are compared with those of the manometer. The airspeed indicator is calibrated in accordance with the adiabatic formula which expresses the relationship between differential pressure and air speed. A table is used which is computed for airspeed against inches of water or inches of mercury. Mercury is also used in the test because of the required pressure in the higher range which could not be attained under practical conditions by using water. The airspeed scale of the mercury manometer starts at 250 mph. To perform the test, progressive readings are obtained (by gradually increasing the pressure) and the errors in the indicator readings compared with the tolerances as specified in the Technical Order. If the error exceeds the tolerance, send the instrument to the depot for overhaul or recalibration.

d. MAINTENANCE. To provide accurate manometer readings, it is essential that the mercury and the tube be cleaned properly.

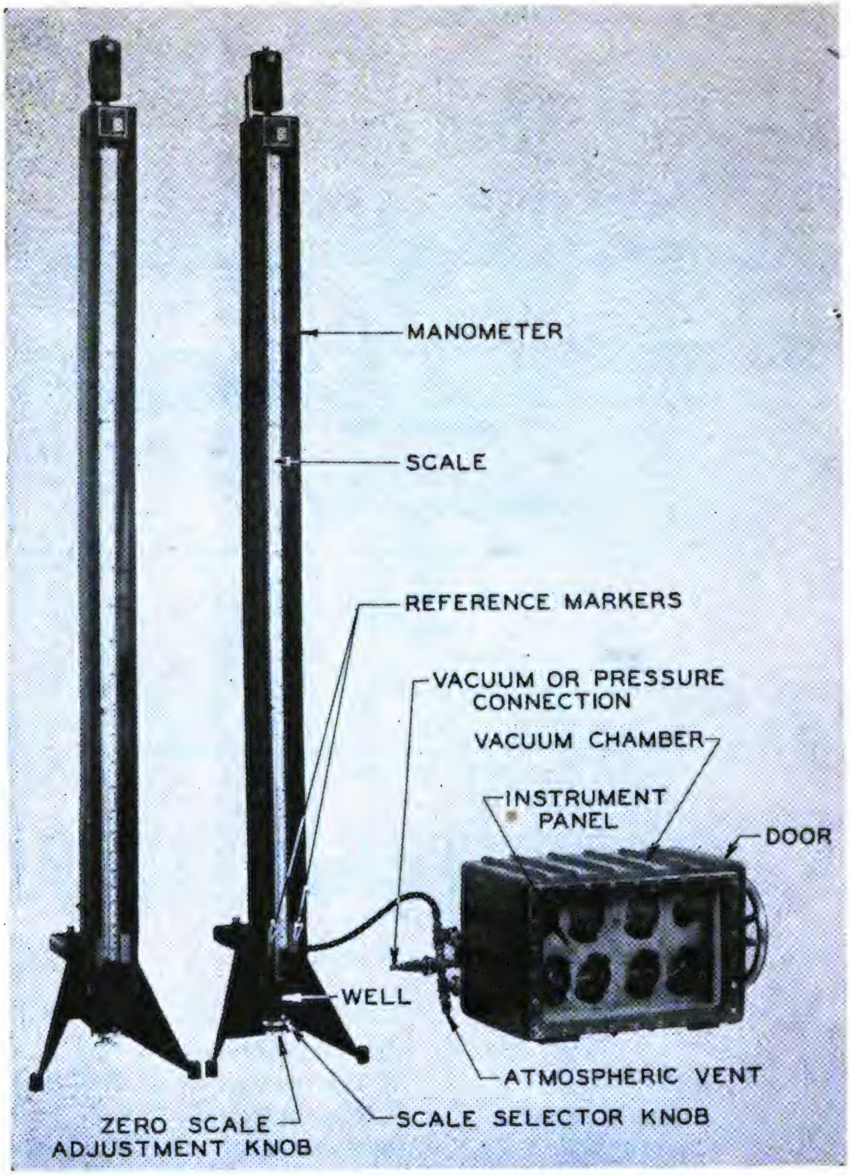


Figure 250. Manometer and vacuum chamber.

(1) *Cleaning mercury.* Mercury may be cleaned by washing with a dilute solution of nitric acid (10 parts acid and 90 parts distilled water) or a solution of sulphuric acid (80 parts acid and 20 parts distilled water). After the mercury has been thoroughly washed and the acid solution removed by filtering, wash the mercury with distilled water, filter off the water and dry the mercury. The preferred method utilizes the arrangement shown in figure 253. The mercury is slowly poured into the funnel. The filter paper (pinholed) removes some of the impurities. The mercury sprays through the small funnel tip and passes through the acid solution. Other impurities are thus removed and the mercury collects in the bottom of the tube. When a sufficient amount of mercury accumulates, the pinch cock is opened and the clean mercury allowed to flow into the beaker. The flow of filtered mercury should be controlled carefully to prevent the flow of acid solution into the beaker; this may be accomplished by allowing a small portion of the mercury to remain in the bottom of the glass tube at all times. The mercury collected in the beaker is next passed through distilled water. If drying is essential, the beaker containing mercury is placed on asbestos over an open flame and heated (not above 110° C.) until all moisture is removed. Alcohol may also be used as a drying agent.

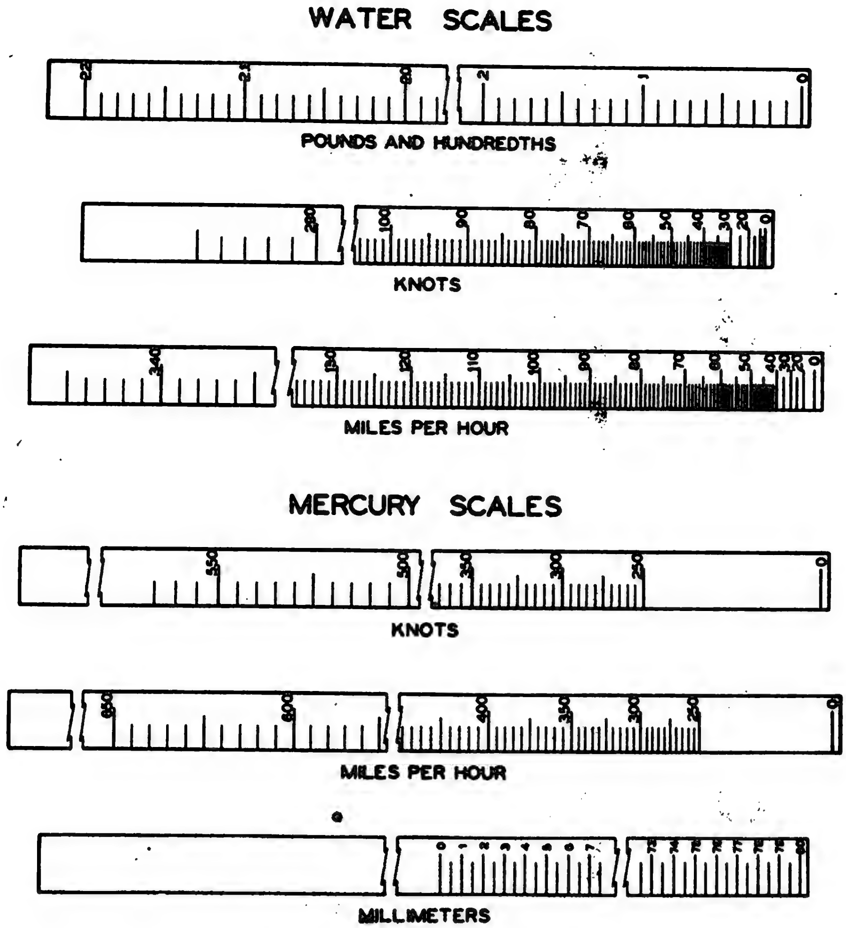


Figure 251. Manometer scales.

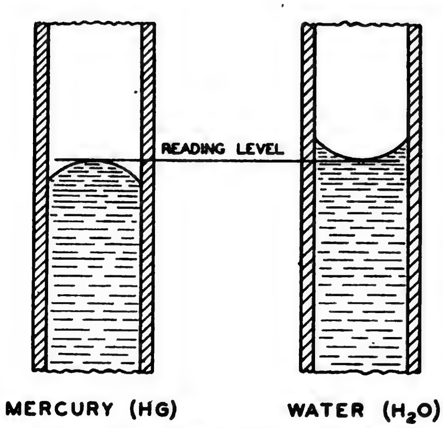


Figure 252. Manometer reading levels.

If the mercury to be filtered has accumulated grease, it should first be passed through a 10-percent solution of potassium hydroxide and the procedure outlined followed, using nitric acid (10 percent).

(2) *Cleaning manometer tubes.* After long periods of operation, the manometer tube often becomes clouded as a result of impurities deposited on the glass. To remove these, a piece of medium stiff piano wire with a swab attached to one end is used. Select a material which will shed a minimum of lint during the swabbing process. Swab the tube with a strong soap solution to which a little ammonia has been added. Next swab the tube with a dilute solution of nitric acid (25 parts nitric acid and 75 parts distilled water). Place the tube against a white background and examine it closely for cleanliness. The clean tube is then rinsed with distilled water and dried with alcohol. When refilling the manometer well, use fluid which does not contain any foreign matter. Pour the liquid into the well until it coincides with the index mark on the manometer.

104. Vacuum Chamber

a. Purpose and Use. The vacuum chamber maintains a condition of reduced pressure and is used for testing various differential-or absolute-pressure instruments.

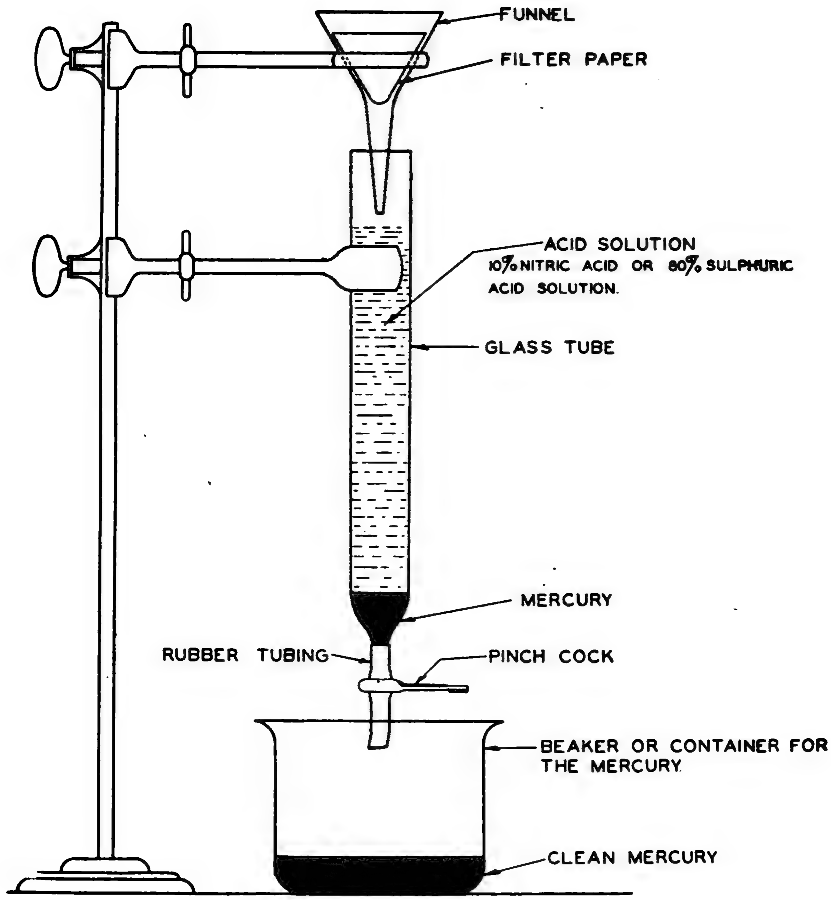


Figure 253. Apparatus for cleaning mercury.

b. Description. The chamber, shown in figure 206, is equipped with a heavy dual safety-glass window through which instruments may be observed; the chamber door is sealed with a rubber gland. Channels within the chamber provide a sliding mount for the instrument panel. Several openings in the panel permit testing a number of instruments simultaneously. On the rear of the panel is a small 110-volt, 60-cycle motor used to produce vibration by means of an eccentric weight attached to the end of the motor shaft. A connection for the motor circuit is provided on the outside of the vacuum chamber and is completed when the panel has been entirely inserted in the chamber. Suitable vents to the inside of the chamber are provided for the attachment of valves and a manometer.

c. Application. (1) Two spring-loaded clamps are used to secure an altimeter to the panel for testing. A rate-of-climb indicator is installed with the altimeter to provide a means of checking the rate of pressure change. When the two instruments have been correctly installed and adjusted, slide the panel into the vacuum chamber, close the door, place the safety latch in the locked position, and rotate the large wheel until an airtight seal is established. The motor is operated and the instruments are ready for testing.

(2) As the pressure in the vacuum chamber is decreased, the readings of the manometer and of the instrument under test are taken. Errors should be within the tolerance specified in the Technical Order applying to the particular instrument.

(3) Detailed instruction for the use of the vacuum chamber to refill and test an aircraft compass is set forth in the Technical Order for the particular compass.

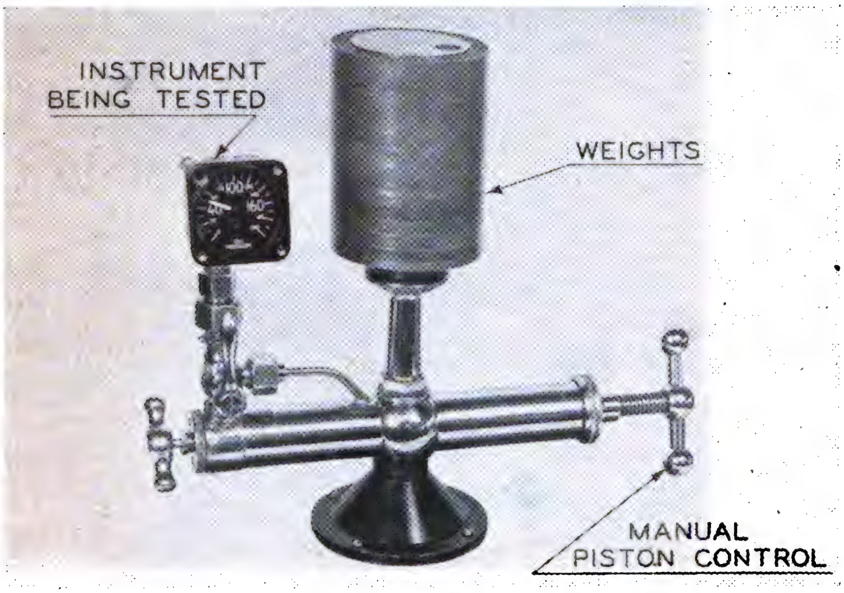
d. Maintenance. (1) The seal around the chamber must be airtight. To maintain an airtight seal, the contacting surfaces of the chamber and the door must be thoroughly clean. The gland should be closely examined for defects. The application of a thin film of glycerin may provide a seal for slight defects.

(2) To avoid damage to the latch on the chamber door, the chamber should never be subjected to more than atmospheric pressure.

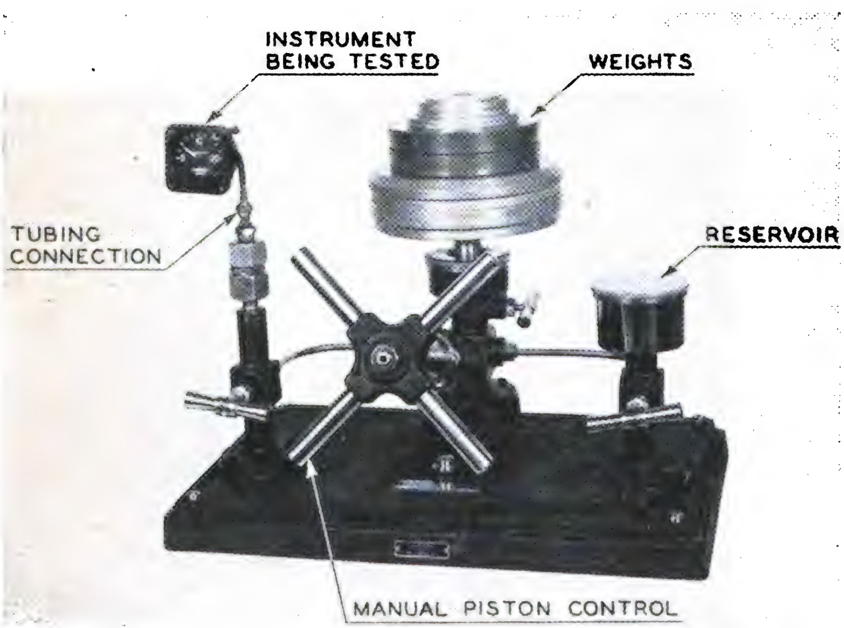
105. Dead-Weight Tester

a. Purpose and Use. The tester is furnished in two ranges: 0 to 200 pounds per square inch, and 0 to 3,000 pounds per square inch. The low-range tester (fig. 254①) is used for testing comparatively low-range pressure gauges and the other (fig. 254②) for those of comparatively high range. The tester is a master gauge for scale-error test. The tests are performed by comparing the readings on the instrument under test with the pressures developed in the tester. The following gauges are calibrated with dead weight tester.

(1) Automatic-pilot oil pressure.
(2) Fuel pressure.
(3) Oil pressure.
(4) Landing-gear pressure.



① *Low range.*



② *High range.*

Figure 254. Dead-weight tester.

b. Description. Figure 254 shows the testers with gauges attached. Fundamentally, both the high and low-pressure testers operate on the same principle. Each unit contains a manually operated piston, reservoir, weight table with piston, attaching fixture, and valves. The weights are numbered 1, 2, 5, 10, etc., which numbers designate respective pressures in pounds per square inch produced when the weights are used with the tester. The pressure in the tester depends upon two factors: the weight used and the cross section area of the piston. Thus, if the weight-table piston has a cross section area of 1/5 square inch, a 1-pound weight would produce a pressure of 5 pounds per square inch.

c. Application. The instrument to be tested is connected to the tester. The cylinder is filled with specified oil, weights placed upon the table, and the manual piston control rotated to increase the hydraulic pressure. When the pressure reaches a value which is sufficient to lift the table from the support, a reading is recorded on the gauge under test. The test procedure and the allowable error in the gauge reading must be as specified in the Technical Order for the particular instrument. During the time the gauge is subjected to pressure no weights should be removed from the tester table.

d. Maintenance. The following rules of maintenance should be observed:

(1) Inspect for, and repair leaks.
(2) Keep unit clean.
(3) Use specified oil.
(4) Store unit in a dry room.
(5) Handle unit and all accessories carefully.
(6) Place all accessories in their respective receptacles.

106. Voltmeters

a. Purpose and Use. A voltmeter measures the voltage or potential difference between two points of an electrical circuit.

b. Description. There are many types of voltmeters. For test purposes the Army Air Forces use d-c, pulsating d-c, and a-c voltmeters. The range of each instrument depends upon its application.

(1) The mechanism of a d-c voltmeter includes a permanent magnet and a movable coil to which a pointer is attached. Actually, a d-c voltmeter is a D'Arsonval type galvanometer with a high resistance connected in series with a movable coil (fig. 255.) This type of instrument utilizes a scale of uniform graduations.

(2) The pulsating d-c voltmeter may be of the dynamometer or rectifier type. The dynamometer type voltmeter (fig. 256) contains a movable coil in series with and (for zero reading) placed at right angles to two stationary coils. A resistance is also connected in series with the coils. The scale has nonuniform graduation. The rectifier type of voltmeter is basically a direct-current instrument adaptable for use with alternating current by the addition of a rectifier. This type of instrument is equipped with a scale of uniform graduations.

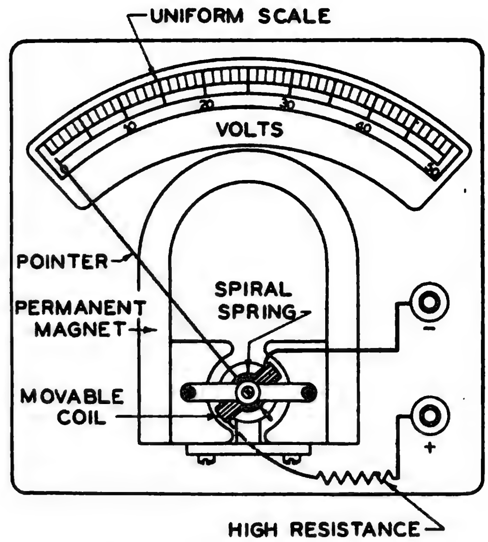


Figure 255. D-c voltmeter.

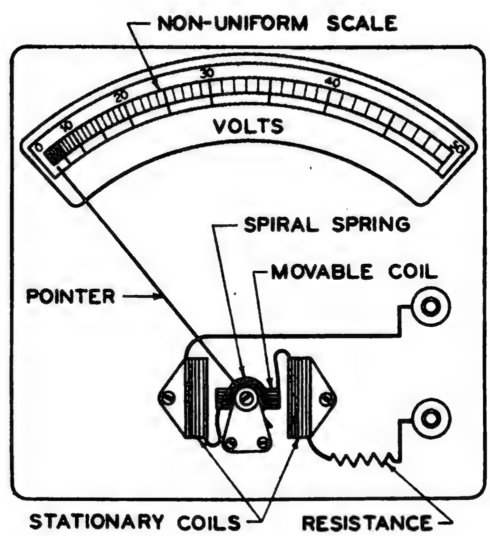


Figure 256. Dynamometer type voltmeter.

(3) The most common a-c voltmeter is the iron-vane type which is sometimes referred to as the movable-iron type. A simplified diagram of this mechanism is shown in figure 257. It contains a cylindrical coil with two laminated

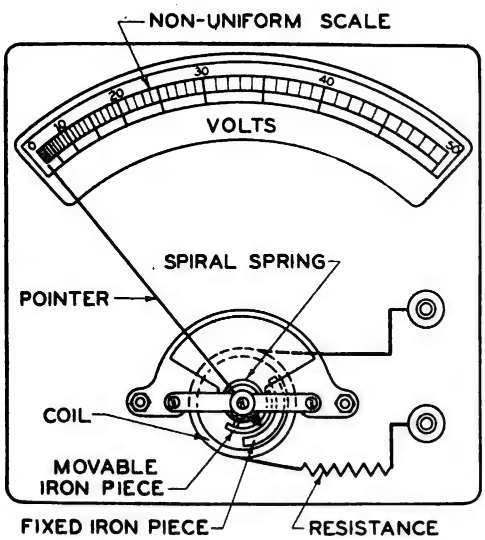


Figure 257. Iron-vane of voltmeter.

iron pole pieces, one fixed and the other movable. The pointer is attached to a movable pole piece. This type voltmeter is equipped with a scale having nonuniform graduations.

c. Application. (1) Figure 258 shows a simple electrical circuit consisting of a source of supply, an ammeter, a resistor or load, and a voltmeter. The ammeter is explained in paragraph 107. Before connecting a voltmeter into the circuit the source of electrical supply (whether alternating current or direct current) and the range of the voltmeter should be noted.

(2) When measuring voltage the proper type of instrument must be used. Most a-c voltmeters (except those which use transformers) can be used to measure direct current. However, in such a case the accuracy of the reading is impaired. The dynamometer type of voltmeter requires about five times as much current as a d-c voltmeter of the same rating and consumes an appreciable amount of power which may also affect the reading. These factors should be taken into consideration when using voltmeters.

(3) When using a multiple-range voltmeter, always place the selector switch in a position to exceed the maximum value of the voltage to be measured. Figure 259② shows a multiple-range voltmeter.

d. Maintenance. (1) A voltmeter requires no lubrication.

(2) Always handle a voltmeter so as to avoid jarring.

(3) Mechanical zero adjustment on the voltmeter is essential for correct indication of the instrument. If at any time (when not in use) the indication is not zero, adjust the pointer with a screw driver so that the pointer is in line with the zero mark.

(4) When doubt exists concerning the accuracy of a voltmeter, check the reading of the instrument against that of another voltmeter

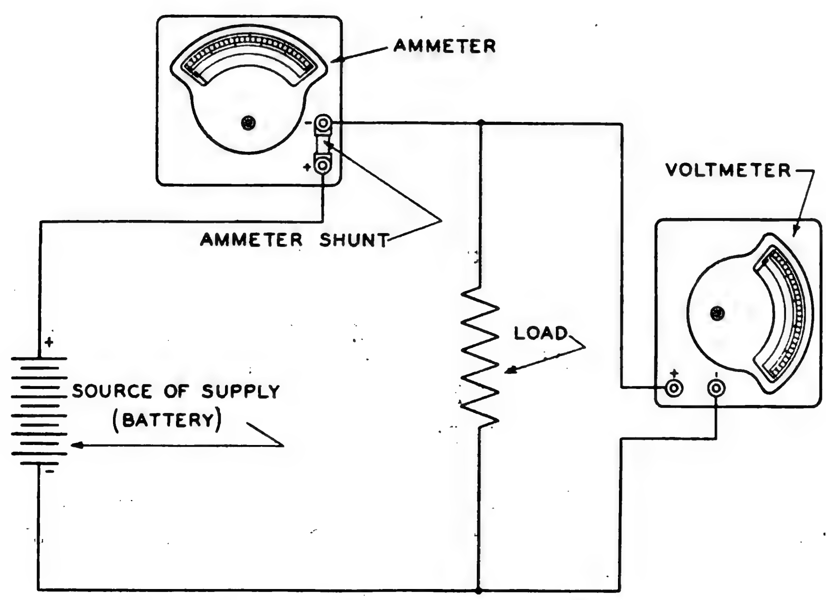
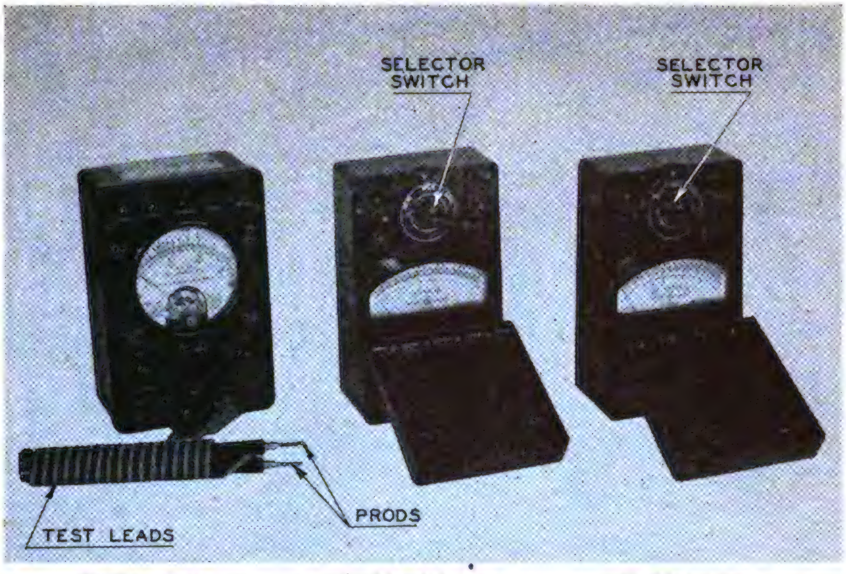


Figure 258. Simple electrical circuit.



① *Ohmmeter (continuity meter).* ② *Multiple-range voltmeter.* ③ *Multiple-range ammeter.*

Figure 259. Electrical instruments for measuring resistance, voltage, and current.

known to be correct; if in error the instrument should be sent to the depot for calibration (deflection potentiometers with volt and shunt boxes are used to calibrate voltmeters and ammeters).

107. Ammeters

a. Purpose and Use. An ammeter is an instrument for measuring current (rate of flow of electricity) in an electrical circuit.

b. Description. (1) The ammeter is similar in construction to the voltmeter. The D'Arsonval mechanism is used for the d-c ammeter, shown in figure 260. The dynamometer and rectifier types of ammeters are used for small current measurement. The iron-vane ammeter is used commonly for large a-c measurement.

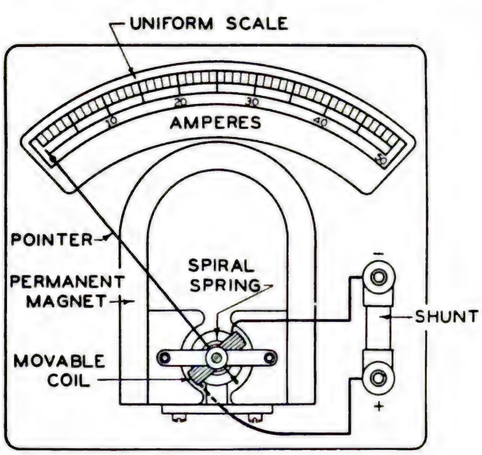


Figure 260. D'Arsonval type ammeter.

(2) To measure large direct currents, an ammeter is connected in parallel with a shunt. A shunt is merely a low resistance which causes the larger portion of current to be diverted from the moving coil of the ammeter. By using shunts of different resistances, it is possible to utilize a number of ammeter scales and ranges. Figure 259③ shows an ammeter which is provided with a selector switch for choice of any of three scale ranges.

c. Application. A simple electric circuit with an ammeter and an external shunt is shown in figure 258. An ammeter must always be connected in series with the load. The resistance of an ammeter is low and if the instrument connected is parallel, serious damage will result.

d. Maintenance. The maintenance outlined for voltmeters in paragraph 106 is also applicable to ammeters.

108. Ohmmeters

a. Purpose and Use. An ohmmeter is an instrument for measuring the resistance of electric circuits or resistors.

b. Description. The direct-reading ohmmeter and precision ohmmeter are the two types used in the Army Air Forces.

(1) The direct-reading ohmmeter (continuity tester) illustrated in figure 259 is provided with a scale for reading the value of the resistance in ohms. The instrument contains a sensitive volt-

meter, a source of electrical supply (battery), and a rheostat. When a resistance is connected in series with a voltmeter and a source of supply, the value of the resistance in ohms is indicated by the decrease in pointer deflection. The scale of the instrument is calibrated in ohms to show directly the value of the resistance.

(2) The precision ohmmeter (fig. 261) is basically a Kelvin double bridge. A simplified diagram is shown in figure 262. This bridge eliminates the effect of contact resistance (present in the Wheatstone bridge) and as a result provides a method of measuring very small resistances.

c. Application. The direct-reading ohmmeter is used on an aircraft to check the continuity of electrical circuits and the approximate resistance of electric thermometer bulbs. Before measuring a resistance, select the desired range, short circuit the instrument prods, and adjust the rheostat for maximum deflection of the indicator (zero ohm reading). This adjustment is necessary to compensate for any variation in the battery voltage and must be performed as each range is selected. Next, place the prods across the resistor (or circuit) to be measured and read the indication on the instrument. The precision ohmmeter is used to measure accurately, resistances of not over 11 ohms. It is frequently used to determine the resistance of bonding.

(1) When using the precision ohmmeter to test a resistor in the range between 1 and 11 ohms, it is necessary to provide two shunts: one between the terminals C_1 and P_1 and the second between C_2 and P_2, figure 261. To obtain accurate results, place the instrument in a level position and connect the unknown resistance (for example thermocouple loads) between the terminals P_1 and P_2. Place the multiplier switch in the correct position. Release the galvanometer pointer by moving the clamp and check the mechanical zero setting. Next, lock the galvanometer key *GA,* press key *BA,* and note the gal-

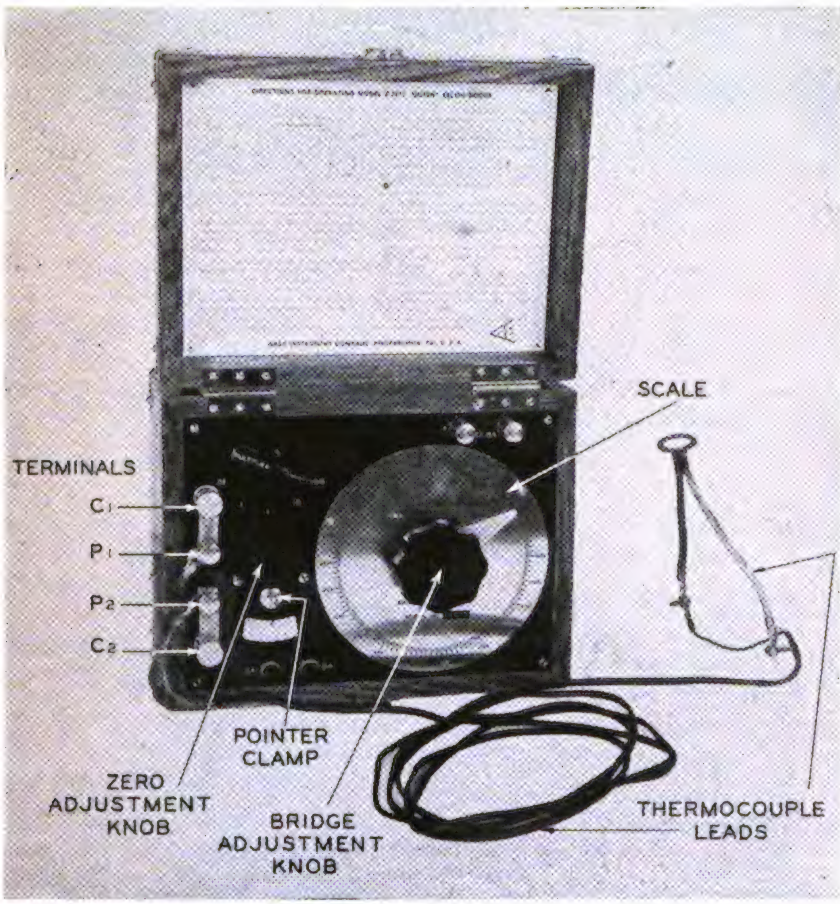


Figure 261. Precision ohmmeter as used for measuring resistance.

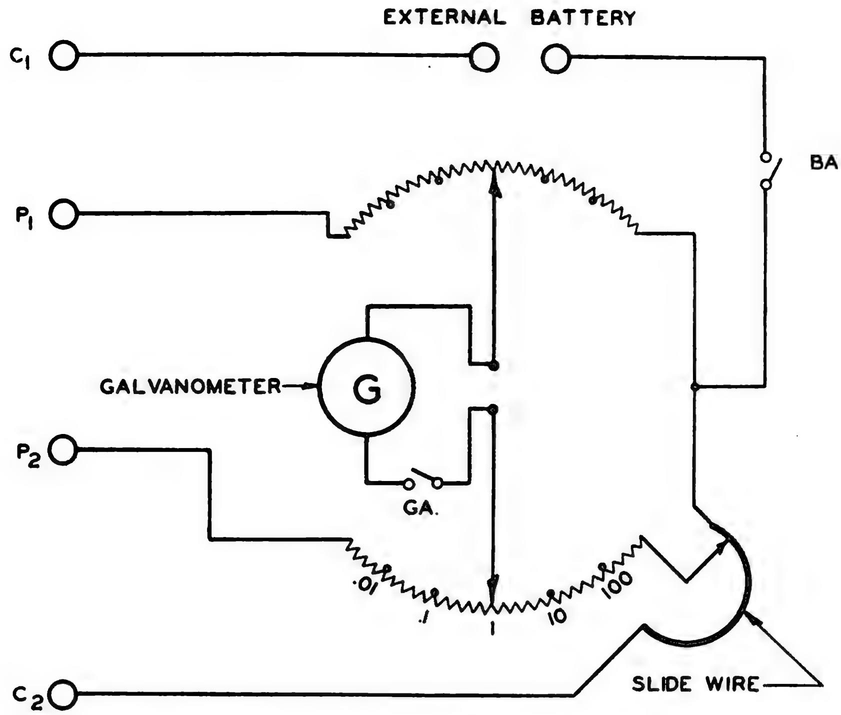


Figure 262. Simplified diagram of Kelvin double bridge.

vanometer deflection. Adjust the bridge and when there is no deflection on the galvanometer the instrument is balanced. The resistance is determined by multiplying the scale reading by the ratio-switch setting (indicated by multiplier).

(2) If it is necessary to use connecting leads between the instrument and the unknown resistance, the resistance of the connecting leads must be determined and subtracted from the total resistance measured by the instrument; the remainder will be the value of the unknown resistance.

(3) When checking the resistance of bonding, remove any oxides from the bonding with emery cloth before proceeding. With clamps and prods in firm contact, as shown in figure 263, the resistance of the bonding is determined as heretofore outlined.

d. MAINTENANCE. It is desirable to inspect instruments of this type periodically to insure accurate results.

(1) To check the precision ohmmeter, use a standard 2-ohm resistance connected between the terminals P_1 and P_2 and proceed as directed

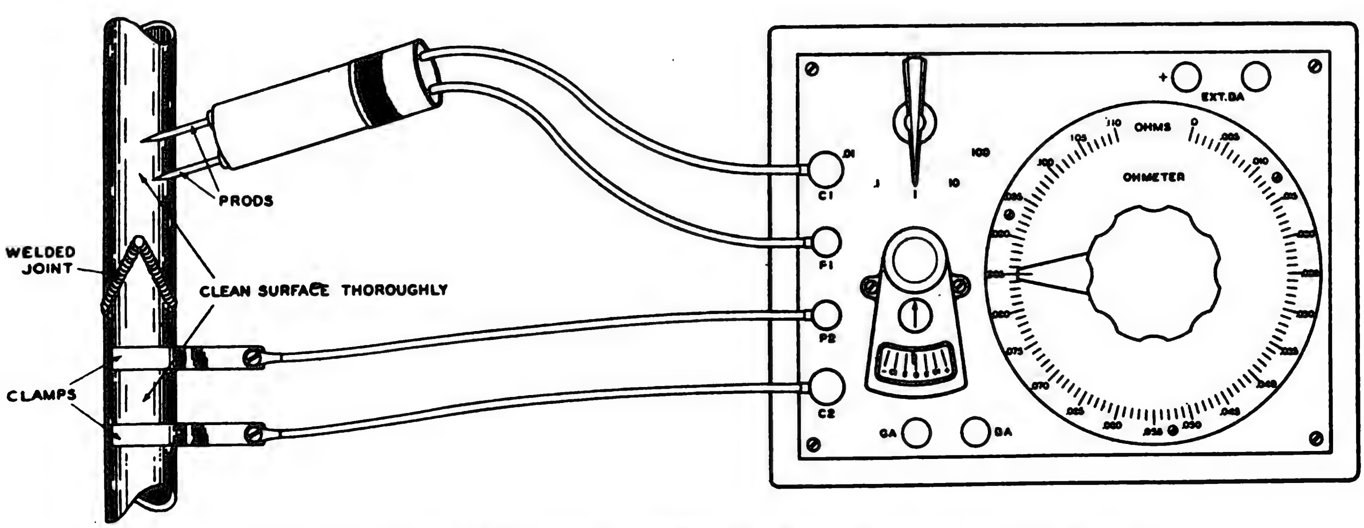


Figure 263. Method of determining resistance of a welded bond with precision ohmmeter.

in paragraph 108c(1). If the reading obtained is satisfactory, it is reasonable to assume that the instrument is accurate within the limits of the scale range.

(2) At times it will be necessary to clean the variable-resistor contact points and switch points. This maintenance is required when erratic and unstable readings are noticeable on the galvanometer. Never use an abrasive to clean the resistor or contact points. Such action will result in the removal of metal, thus changing the resistance of the resistor and impairing the accuracy of the instrument. Resistors and contact points should be wiped with a clean cloth dampened with benzine; this should be followed with application of a cloth greased with a small quantity of petroleum jelly. Any excess jelly should be removed.

(3) The precision ohmmeter is a very sensitive instrument and should be protected against jarring or bumping. When not in use, the galvanometer pointer should be locked with the clamp provided on the instrument. The precision ohmmeter must not be lifted or carried by grasping the carrying-case lid as the hinge pins slide out of the hinge with a lateral movement.

109. Thwing Potentiometer

a. Purpose and Use. The potentiometer is an instrument used for accurately measuring and comparing voltages. As applied to aircraft, the primary use is in the performance of scale error tests upon a synchronism indicator and a cylinder head temperature indicator, provided the voltage to be measured does not exceed 0.1 volt (100 millivolts).

b. Description. The Thwing potentiometer is entirely self-contained and includes necessary batteries and a standard cell. Figure 264 shows simplified potentiometer circuit. The standard cell is the source of comparative voltage. At no time should the standard cell be used as a source of supply for testing an instrument. This cell is a vital part of the instrument and its misuse will terminate the useful application of the potentiometer until the cell is replaced. On the Thwing potentiometer the M_1 rheostat dial reads in multiples of 10 millivolts; the M_2 rheostat dial has a range of 11 millivolts with graduations of 0.05 millivolt.

c. Applications. Figure 265 shows a Thwing potentiometer properly connected to perform a

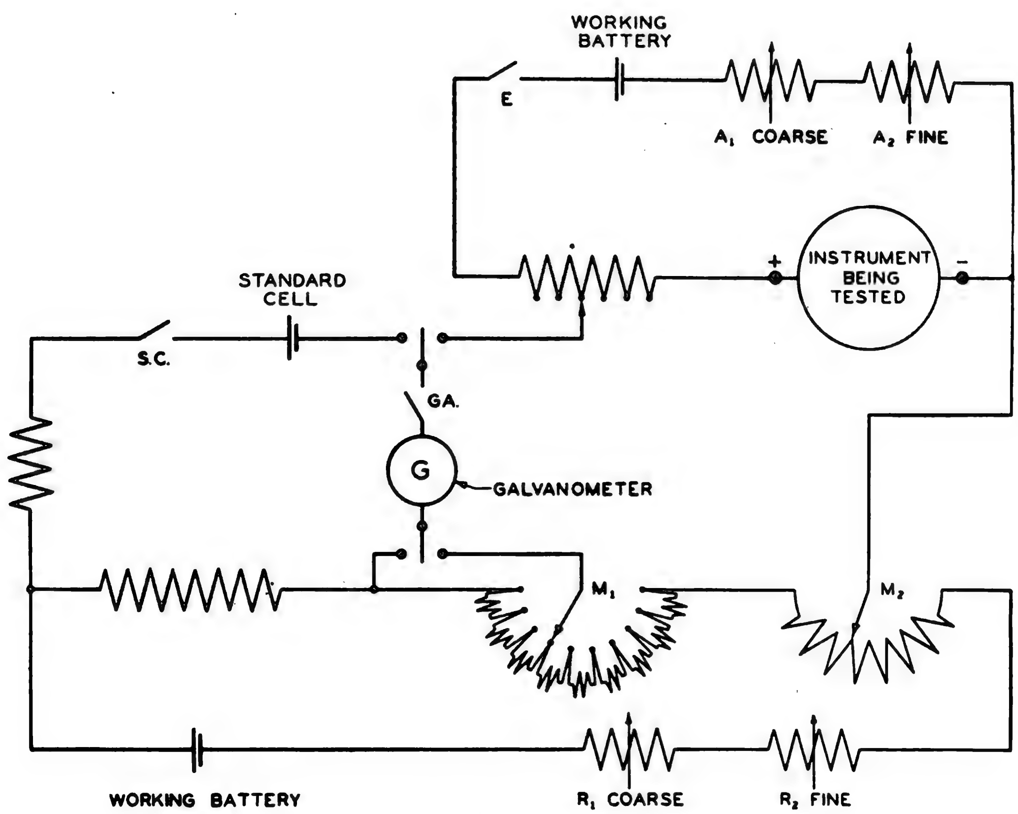


Figure 264. Simplified wiring diagram of potentiometer.

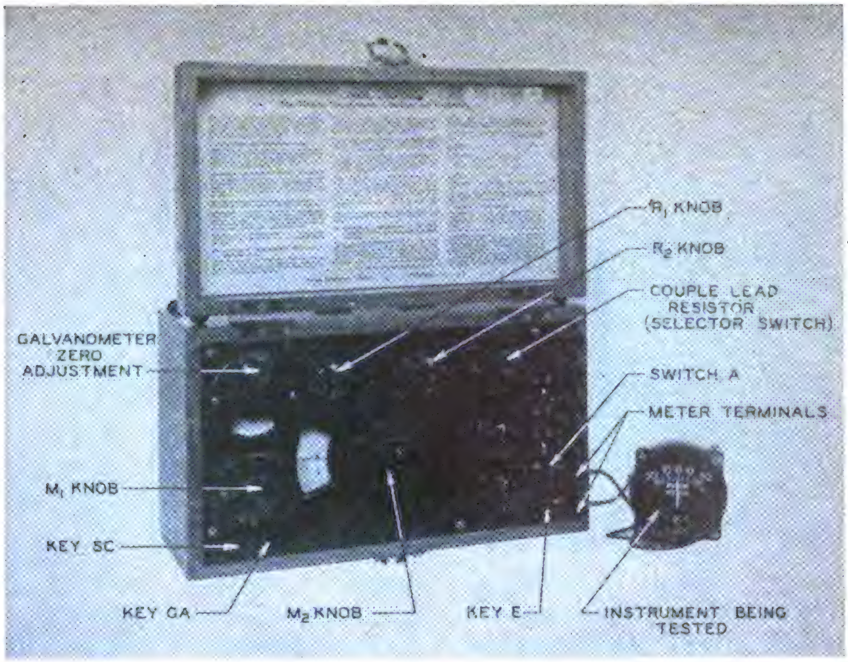


Figure 265. Thwing potentiometer.

scale-error test on a synchronism indicator. Before proceeding to conduct this type of test, it is advisable to consult the Technical Order for the specific instrument to obtain tolerances and details (including the correct value of lead resistances to be used). However, the maximum voltage required for full-scale deflection of the instrument to be tested must not exceed 0.1 volt as this is the range limit of the Thwing potentiometer. After checking the mechanical zero of the instrument, connect its positive (+) and negative (—) terminals to the correspondingly marked terminals of the potentiometer.

(2) To operate the potentiometer, check the mechanical zero setting of the galvanometer. Place switch A in the "Open" (up) position and perform the electrical zero adjustment by varying rheostats R_1 (coarse adjustment) and R_2 (fine adjustment), observing the reading with the keys SC and GA in their "Closed" positions. The galvanometer pointer will give a zero indication when the instrument is properly balanced.

(3) Set the couple lead resistance (selector switch) to the number nearest to the value of the lead resistance specified in the Technical Order. Lock (by depressing and rotating) key E in the "On" position. The equipment is now ready for a scale-error test.

(4) Adjust rheostats A_1 (coarse adjustment) and A_2 (fine adjustment) to locate the pointer of the instrument being tested on the first test point on the scale.

(5) To determine the voltage across the terminals of the instrument, place switch A in the "Closed" (down) position. Balance the potentiometer by tapping galvanometer key GA and adjusting rheostats M_1 and M_2 until the galvanometer pointer shows no deflection when the key GA is held down. The sum of the readings of M_1 and M_2 indicates the applied voltage in millivolts. The difference between the sum of the readings of rheostat dials M_1 and M_2 and the number of millivolts specified in the Technical Order should be within the limits of the specified tolerance. The procedure outlined is followed for all the test points on the instrument.

(6) As the pointer of the synchronism indicator may be deflected to the left or right, a recommended procedure is to set at one test point (either left or right) and reverse the meter terminals on the potentiometer to obtain the corresponding test point on the opposite side of the scale. This makes two separate tests on the instrument unnecessary.

(7) After completing a test with the Thwing potentiometer, release key E to avoid closing the instrument lid with this key in the "On" position.

d. MAINTENANCE. Maintenance as set forth for the precision ohmmeter (par. 108) is applicable

to the Thwing potentiometer. The potentiometer must not be lifted or carried by grasping the carrying case lid.

110. Decade Box

a. Purpose and Use. A decade box provides a resistance which may be varied by tenths, units, tens, hundreds, and thousands of ohms. The decade box is suitable for use where precise resistance is required for testing electrical instruments.

b. Description. Figure 266 shows a simplified wiring diagram of a decade box. A resistance of 0.1 to 9999.9 ohms may be obtained with this unit.

c. Application. (1) The decade box (fig. 267) may be substituted for a resistance bulb when an electric thermometer is tested. With the instrument attached to a source of voltage and the decade box set for resistance as specified in the Technical Order for the particular instrument, check the instrument readings. They should be within the tolerance specified in the Technical Order.

(2) Before voltage is applied to the circuit in which the decade box is used, sufficient resistance must be set (in the box) to prevent an excessive flow of current.

d. Maintenance. Oxides and other impurities should be removed from contacts and contact arms to eliminate a source of error. Contacts and contact arms may be cleaned as outlined for the precision ohmmeter. (See par. 108.)

111. Vapor-Pressure Thermometer Tester

a. Purpose and Use. This tester is used to perform a scale-error test on a vapor pressure thermometer. It has a range of from −40° C. to 200° C.

b. Description. The thermometer tester (fig. 268) is a compact device with a complete refrigerating unit and a two-tube container (evaporator) in which the vapor-pressure thermometer bulbs are placed. The refrigerating unit consists of a two-cylinder, air-cooled, reciprocating compressor driven by a ⅓-hp, 110-volt, 60-cycle, single-phase motor. The refrigerant (liquid) is nontoxic, nonflammable, and noncorrosive. The container houses the cooling coil, electrical heating element, and a liquid which will not freeze at −40° C. nor boil at 200° C. The liquid transfers heat from the thermometer to

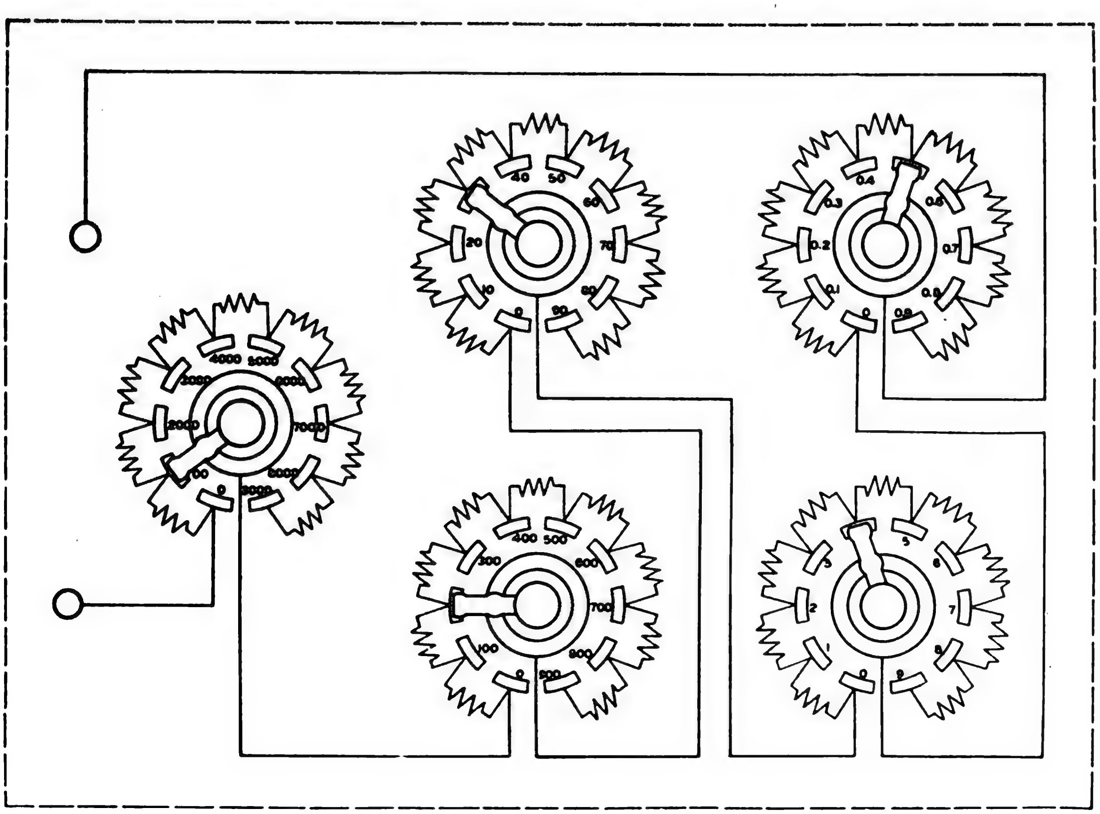


Figure 266. Simplified diagram of decade box.

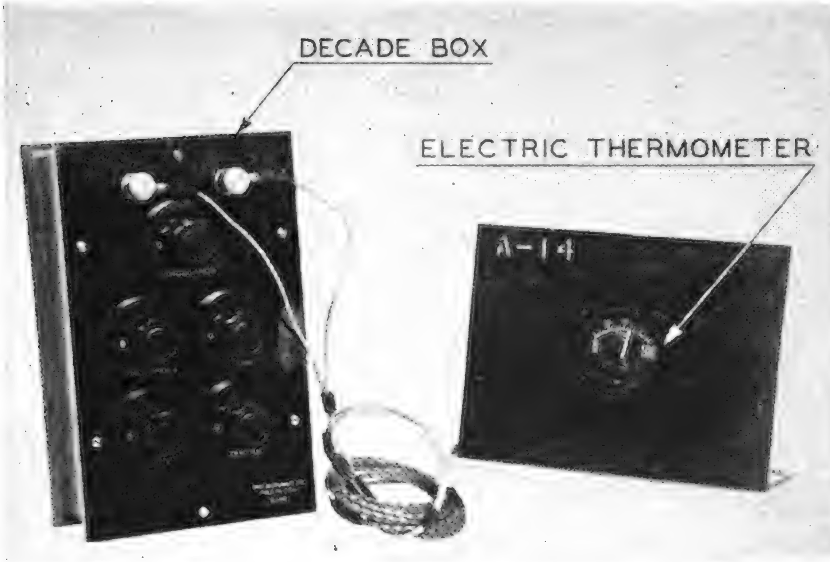


Figure 267. Decade box for thermometer test.

the cooling coil, or from the heating element to the thermometer bulb. A thermostat, a pressure control, and refrigerant safety control are provided for regulation of cold and heat cycles.

c. Application. Insert the bulb of the thermometer to be tested in one well of the tester, and the bulb of a master thermometer in the other well.

(1) *Cold cycle.* Before operating the tester for a cold cycle, place all switches in the "Off" position. Then, place the main switch in the "On" position. Next, place the cold switch in the "On" position. This starts the refrigerating unit. Note the reading on the compound gauge. During the first cycle of operation of the refrigerating unit, a pressure between 20 and 70 pounds per square inch is registered on the compound gauge. After the compressor has been in operation for a few minutes, the indicator pointer will drop below zero to the vacuum side. Next, place F-12 liquid switch in the "On" position. This allows refrigerant to enter the cooling coil in the evaporator. When the F-12 liquid switch is in the "On" position the left pilot light is

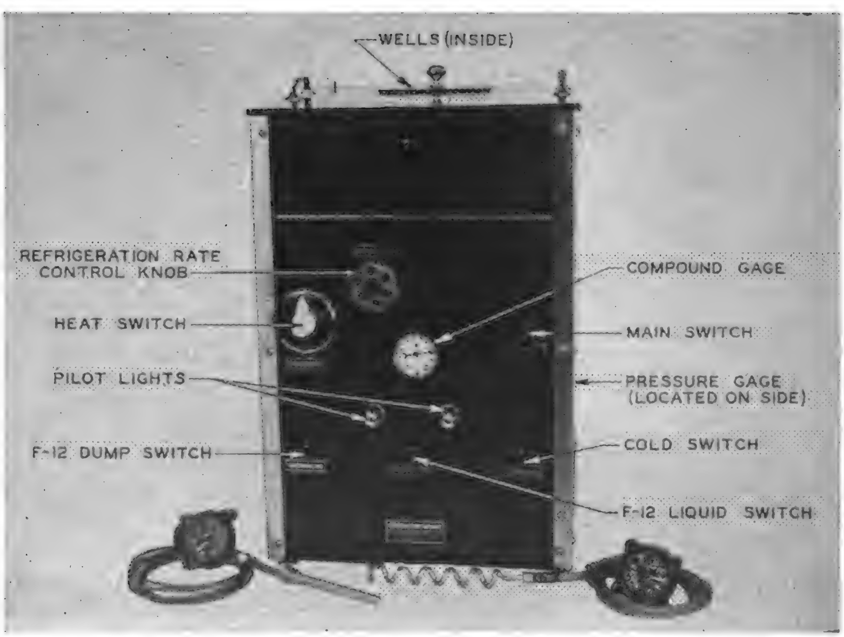


Figure 268. Vapor-pressure thermometer tester.

illuminated. This light remains illuminated during the period the tester operates on a cold cycle. A pressure gauge is located on the right side of the tester when viewed from the front. During early operation, this gauge will register from 120 to 150 pounds per square inch, and the indication will gradually recede to 90 pounds per square inch at —40° C. Readings may now be taken on the instrument under test and compared with those of the master thermometer. In each case, the error of the instrument under test shall be within the tolerance specified in the Technical Order for the particular instrument. The cooling rate is rapid at the beginning of the cold cycle and decreases slowly in the range from 0° C. to —40° C. If the cooling rate is too rapid to compare accurately readings of the instrument under test with those of the master thermometer, open the refrigeration rate-control valve slightly to reduce the rate of cooling. When it is desired to stop operation of the cold cycle, all switches are placed in the "Off" position.

(2) *Heat cycle.* Before operating the tester for a heat cycle, place all switches in the "Off" position. Then place the main switch in the "On" position. Next, turn the heat switch to the "High" position. The right pilot light will remain illuminated during the heat cycle. The temperature will rise until 200° C. is reached. If the rate of heating is too rapid to compare accurately, readings between the master thermometer and the instrument under test, place the heat switch to the "Medium" or "Low" position. If any amount of refrigerant is left in the cooling coil when heat is applied, a high pressure will result (indicated on the compound gauge). The F-12 dump switch should be left in the "On" position to prevent building up an excessive pressure in the cooling coil and in the low side of the compressor. After completion of the heat cycle, all switches should be placed in the "Off" position. The usual procedure is to test a thermometer with the cold cycle and complete the test with the use of the heat cycle. To avoid damage to the tester when the heat cycle is accomplished first, the cold cycle must not be placed in operation until the liquid has cooled to room temperature. When doubt exists concerning any phase of operation of the tester, the manufacturer's operating instructions should be consulted.

d. MAINTENANCE. The following apply to maintenance of the tester:

(1) Slippage of the V-belt may be minimized by application of castor oil to sides of the belt.

(2) Condenser should be blown out with compressed air at intervals of 3 months.

(3) Do not permit lint or dust to collect in the fan.

(4) Motor bearings should be oiled at intervals of 6 months.

(5) Compressor need not be lubricated.

(6) A suitable inspection, lubrication, and maintenance record should be kept.

112. Analysis Cell-Test Box

a. PURPOSE AND USE. This instrument is used to test the analysis cell of a fuel-mixture indicator for electrical zero adjustment. In some instances it may be necessary to use the test box to heat the filaments of the analysis cell to remove the carbon residue.

b. DESCRIPTION. The test box (fig. 269) contains four 1½-volt dry cells, a milliammeter, galvanometer (microammeter), rheostat with switch two toggle switches, four receptors (numbered 1, 2, 3, and 4), and four sets of leads (to accommodate the various types of analysis cells). All leads in each set are banded conveniently for guidance of the operator.

Figure 269. Analysis-cell test box.

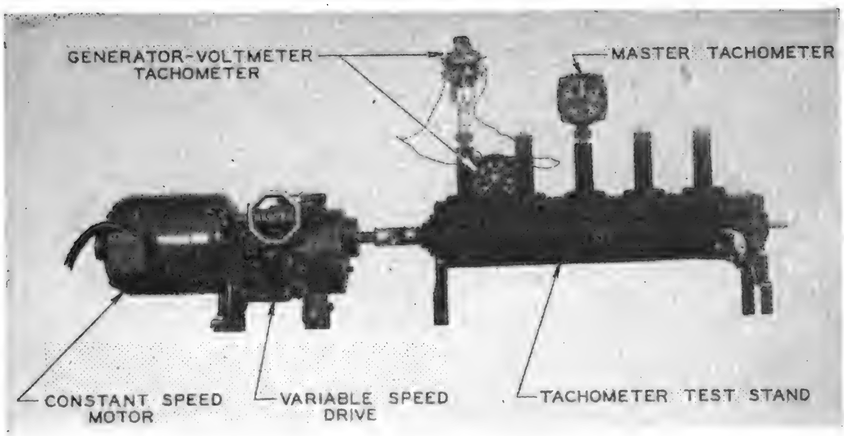


Figure 270. Tachometer test stand.

c. Application. (1) Read carefully the operating instructions accompanying each test box and consult the Technical Order for the particular analysis cell for details and wiring diagrams. To protect the galvanometer of the tester, it is recommended that a continuity meter be used to check the bridge in the analysis cell for open spirals (resistors).

(2) Before completing any connections, place all switches, including the rheostat switch, in the "Off" position. Select the proper set of test leads, attach the cannon plug (or alligator clips if the cannon plugs are not suitable) to the analysis cell, and place the banana plugs in their respective receptors. The banding (used for numbering) on the leads shows continuity of the wire and should not be confused with the numbers on the analysis cell. Place the galvanometer switch in the "On" position and observe the pointer. If there is any deflection, the bridge in the analysis cell is unbalanced and requires an adjustment. As the adjustment for different type cells vary, the Technical Order for the particular cell should be consulted for details. When adjusted, the galvanometer should indicate zero.

(3) If accurate adjustment cannot be made, carbon residue may have accumulated on the spirals in the cell. In many instances this residue may be removed by using the test box to heat the filaments of the analysis cell. The Technical Order for the particular cell and the operating instructions for the test box should be consulted for the correct value of current to be applied and the length of time it may be applied. Before applying the heating current to the analysis cell, place the galvanometer switch in the "Off" position. This is to prevent damage to the galvanometer. Then place the battery switch in the "On" position and adjust the current to the desired value by means of the rheostat. If the cell incorporates a ballast tube, a special procedure must be followed, as outlined in the instructions accompanying the test box.

d. Maintenance. (1) The test box requires no periodic maintenance. If the voltage decreases to a value which does not permit sufficient operating current, replace the dry cells.

(2) Protect the instrument from dampness and jarring.

(3) When not in use, the switches and rheostat should be in the "Off" position.

113. Tachometer Test Stand

a. Purpose and Use. The tachometer test stand, shown in figure 270, is used for scale-error tests on centrifugal, chronometric, or electric tachometers.

b. Description. (1) The test stand has a housing which contains the primary gear mechanism for the operation of five vertical spindles. A master tachometer, usually of the chronometric type, is attached to one of these spindles. The main drive shaft extends through the ends of the housing; and adapter protrudes from the rear side of the housing and is used as an auxiliary drive.

(2) The tachometer test stand may be operated by a variable-speed motor or a constant-speed motor equipped with variable-speed drive.

c. Application. Figure 270 shows the assembly with a generator-voltmeter tachometer installed for testing. To prevent damage to the instruments attached to the stand, the variable drive

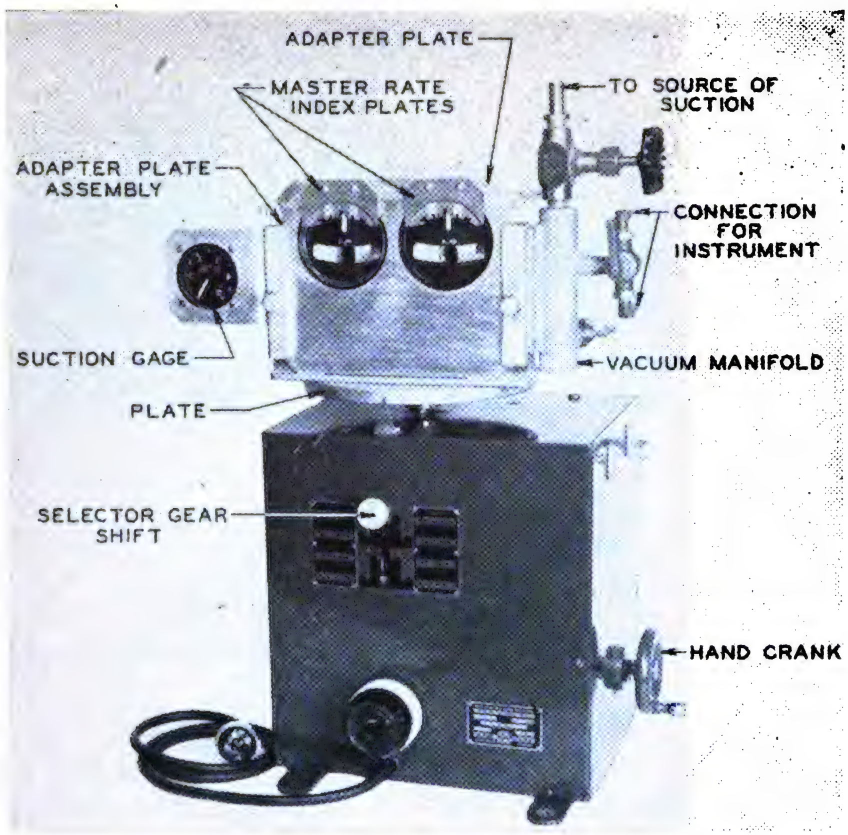


Figure 271. Turntable assembly.

(or variable-speed motor, if used) must be placed in the "Slow" speed position before starting. Adjust the speed so that the master tachometer indicates the rpm specified in the Technical Order for the tachometer under test. Compare the readings of the master tachometer and the aircraft tachometer at specified speeds. If the readings of the master and aircraft tachometer differ by more than the tolerance specified in the Technical Order, the instrument should be returned to the depot for repairs.

d. Maintenance. Required maintenance is as follows:

(1) Keep the unit clean.

(2) Inspect for and repair leaks.

(3) Lubricate, as needed, the gear mechanism of the test stand and the drive unit.

114. Turntable Assembly

a. Purpose and Use. The turntable assembly (fig. 271) is designed to rotate a plate about a vertical axis at a selected rate of speed. It is used for testing a bank-and-turn indicator.

b. Description. The turntable assembly contains a gear train with gear ratios to govern the speed of the turntable. A selector gear shift is employed to obtain four distinct rates of rotation ranging from 36 to 1,080° per minute. Right or left turns are obtained by setting the selector gear shift to the right or left of the neutral position. An adapter-plate assembly, complete with vacuum manifold, hose connections, valves, suction gauge, and special clamps, is located on the plate of the unit. The plate is attached securely to the drive shaft to insure correct alignment. When testing an aircraft compass, a special adapter plate for each type is used to simulate aircraft installation.

c. Application. (1) *Bank-and-turn indicator.* Properly affix the instrument to be tested to the turntable assembly and complete the connections to a vacuum source. Next, adjust the suction setting to the value specified in the Technical Order for the instrument, and allow the gyroscopic rotor to attain operating speed. Place the selector gear shift in position for the desired direction of rotation and turntable speed, and start the electric motor. Observe the pointer deflection with respect to the master rate index plate. The error in deflection must be within

the tolerance specified in the Technical Order for the instrument. If a damping sensitivity adjustment is required, turn the adjusting screw slightly, again check the instrument on the turntable assembly, and repeat the adjustment and check until the indication is within the tolerance.

(2) *Magnitude-of-turn indicator.* Affix the instrument to a proper adapter, paragraph 114, and mount on the adapter-plate assembly. Connect the instrument to a source of vacuum, adjust the suction to the desired value, and allow the gyroscopic rotor to attain full speed. Set and uncage the instrument knob, place the selector gear shift of the turntable assembly to desired turntable speed of rotation, and start the motor. The error in the indication must be within the tolerance specified in the Technical Order for the instrument.

Figure 272. Damping test of pilot's compass.

Figure 273. Damping test of navigator's compass.

(3) *Compasses.* When conducting a damping test, mount the instrument as shown in figure 272 and 273 (depending upon the type of compass) and allow the compass neeedle to cease oscillating. With the selector gear shift placed in position for desired turntable speed of rotation, permit the turntable to move through one complete revolution and note the position of the card in degrees at the completion of the turn. The error in the reading must be within the tolerance specified in the Technical Order for the instrument.

d. Maintenance. The following rules of maintenance should be observed:

(1) Keep the unit clean.

(2) Use and store the unit in a clean, dry room.

(3) Generally inspect unit and accessories.

(4) Lubricate the unit as needed.

(5) Handle the unit and all accessories carefully.

(6) Keep a record of inspection, lubrication, and maintenance.

115. Gyroscopic Instrument Test Fixture

a. Purpose and Use. This fixture (fig. 274), is used for performing tests on the magnitude of turn indicator and the flight indicator.

b. Description. The fixture consists of a swivel frame with provision for two individual mounting-plate adapters which may be secured in a sliding groove by means of knurled thumbscrews. The instrument affixed to the mounting-plate adapter may be rotated about the lateral, vertical, and longitudinal axes. A vacuum manifold with suitable valves and attachment fittings is affixed to the rear of the fixture. A suction gauge is located on the left side of the fixture.

c. Application. (1) The fixture must be mounted in a level position and firmly attached to the test bench. Fasten the instruments to the mounting-plate adapters, complete all necessary connections to the vacuum source, and adjust the suction to a value as specified in

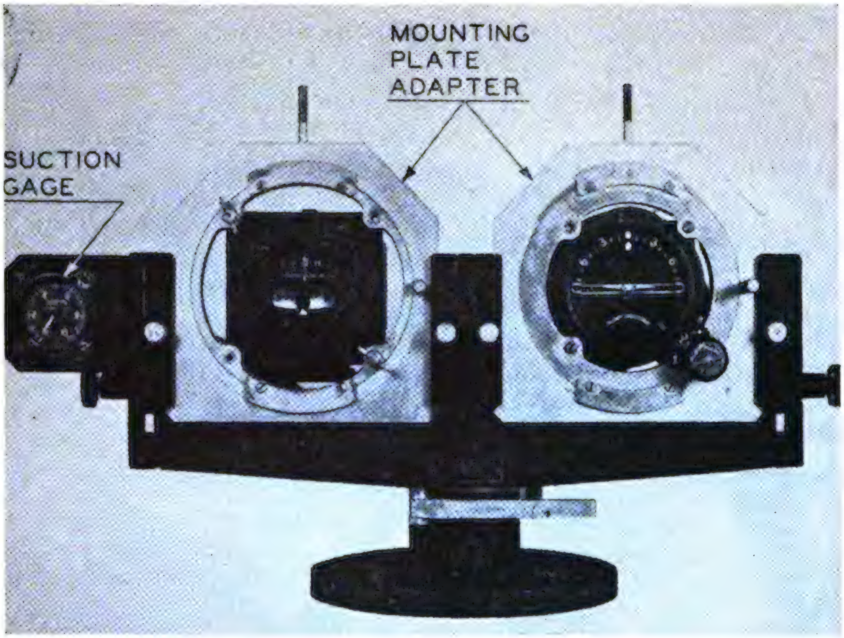


Figure 274. Gyroscopic instrument test fixture.

Technical Orders for the particular instrument under test.

(2) Perform the test procedure for each instrument as outlined in the Technical Order. The error should be within the specified tolerance.

d. MAINTENANCE. Handle and clean the fixture and accessories carefully.

116. Portable Vacuum-Pump Assembly

a. PURPOSE AND USE. The portable vacuum-pump assembly, as shown in figure 275, provides vacuum for testing gyroscopic instruments in the shop or in the hangar.

b. DESCRIPTION. This assembly contains a single-phase, 110-volt, 60-cycle electric motor (⅓-hp), coupled to a vane type vacuum pump which in turn is connected to an oil-air separator by a sight-glass connector which serves to indicate the flow of oil for pump lubrication. Suitable valves and nipple connections (for the attachment of rubber hose) are provided.

c. APPLICATION. Connect rubber tubing from the vacuum inlet to the fixture or instrument line. When the vacuum-relief valve on the aircraft is used to adjust the volumetric flow, regulate the valve to secure the maximum rate of flow, thereby reducing the lead on the pump. Observe the suction gauge to determine whether vacuum as specified in the Technical Order for the particular instrument is being obtained.

d. MAINTENANCE. (1) Consult the Technical

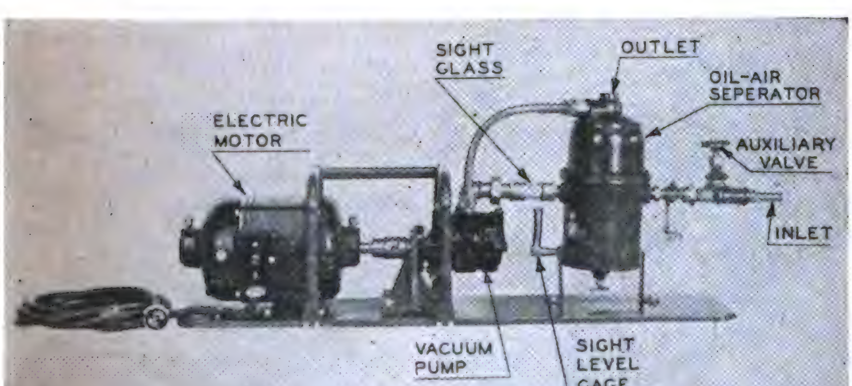


Figure 275. Portable vacuum pump.

Order for the portable vacuum pump to obtain information concerning the grade of oil to use under various operating conditions.

(2) Inspect the motor brushes for correct length, and check the commutator for cleanliness. Supply lubricant to the motor as needed.

(3) Maintain sufficient oil in the reservoir of the oil-air separator.

117. Portable Oil-Pump Assembly

a. Purpose and Use. The portable oil pump provides oil pressure when performing various inspections and adjustments on the hydraulic system of the automatic pilot. The pump makes ground operation of the aircraft engine unnecessary.

b. Description. The pump assembly (fig. 276) contains a single-phase, 110-volt, 60-cycle motor (1/3-hp), coupled to a vane type oil pump. Two flexible sections of rubber tubing are provided for necessary connections.

c. Application. (1) When inspecting the hydraulic system of an automatic pilot in an aircraft installation, disconnect the hydraulic line connections at the hydraulic power pump and substitute the portable oil pump for the power pump. Connect the pressure side of the portable oil pump to the pressure side of the hydraulic system.

(2) Mount the unit securely on a suitable stand.

d. Maintenance. (1) The pump is self-lubricating and requires no periodic maintenance.

(2) Inspect the motor brushes for correct length, and the commutator for cleanliness. Lubricate the motor bearings with the proper lubricant as needed.

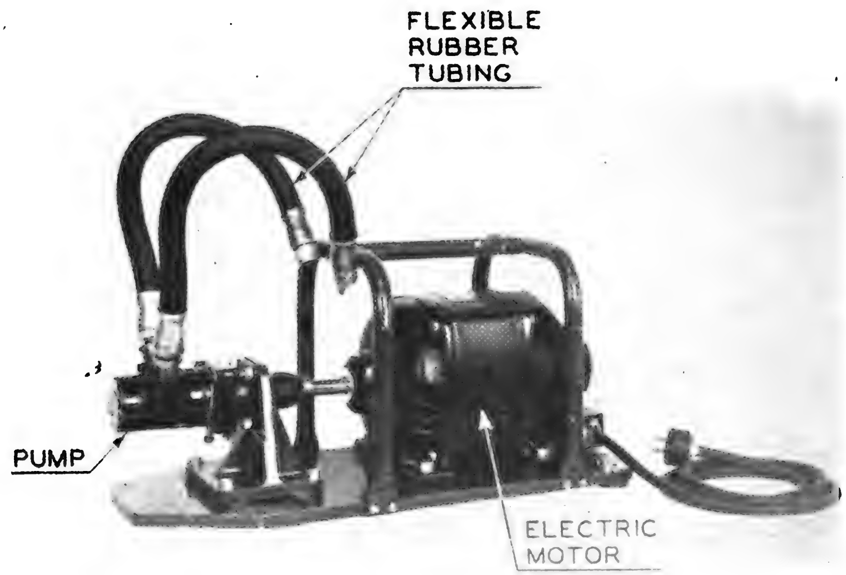


Figure 276. Portable oil pump.

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